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**EFFECTS OF SEDIMENT PULSES ON CHANNEL MORPHOLOGY AND
SEDIMENT TRANSPORT IN A GRAVEL-BED RIVER**

By

Daniel F. Hoffman

B.S., University of Montana

Presented in Partial Fulfillment of the


Requirements for the Degree of

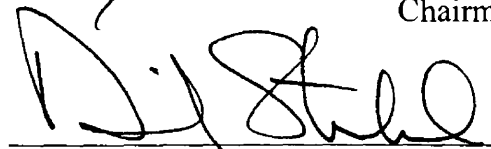
Master of Science

The University of Montana

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Effects of Sediment Pulses on Channel Morphology and Sediment Transport in a Gravel Bed River

Chairman: Emmanuel Gabet 

Sediment delivery to stream channels in mountainous basins is strongly episodic with large inputs of sediment typically delivered by infrequent landslides and debris flows. Identifying the role of large but rare sediment delivery events in the evolution of channel morphologies and fluvial sediment transport is crucial to an understanding of the development of mountain basins.

In July of 2001, intense rainfall triggered numerous debris flows in the severely burnt Sleeping Child watershed, Sapphire Mountains, Montana. Ten large debris flow fans were deposited on the valley floor. Investigations focused on the channel response to the large input of sediment. The channel has aggraded immediately upstream of the fans, and braided in reaches immediately downstream. Channel incisement through the fans has created sets of coarse-grained terraces. The deposition upstream of the pulses consists almost exclusively of fine material resulting in a median bed material size (D_{50}) 1-2 orders of magnitude lower than the ambient channel material. The volume of sand being transported is so great that these aggrading reaches can extend hundreds of meters upstream of the pulses with 1-2 meters of sand deposited across the entire valley floor. In a 10 kilometer study reach with 10 debris flow fans, cross section surveys, longitudinal profiles, and pebble counts chronicle channel response to a major increase in sediment supply and provide insight on the processes of sediment wave dispersal.

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INTRODUCTION

The morphology of a stream channel is an expression of the supply of water and sediment available to it. If the discharge and the supply and character of sediment were held relatively constant over a long enough time period, the channel morphology would be adjusted to it. Channel response to sudden, episodic changes of sediment supply can lead to the establishment of a new channel morphology or a return to pre-disturbance conditions. The delivery of sediment to rivers and streams in mountain drainage basins often comes in large, infrequent pulses from landslides and debris flows. This sediment supply regime differs from that of channels in lowland environments with a more regular sediment supply and is reflected in the form and textural composition of the channel and floodplain. Processing large pulses of sediment can be slow and leave a lasting legacy on the valley floor. Identifying how channels process these sediment inputs is critical to an understanding of the morphological development of mountainous landscapes.

This investigation examines the response of a stream channel to a large, sudden increase in sediment supply and presents a conceptual model of sediment pulse effects on channel morphology and sediment transport processes. Intense rainfall in July 2001 triggered 10 debris flows that deposited fans of coarse and fine sediment in the channel of Sleeping Child Creek (SCC). This provides an opportunity to chronicle channel response to large sediment inputs soon after the initial input and observe how the channel has begun to process the sediment.

One of the most obvious effects of a large sediment input is a change in channel form. Griffiths (1979) noted channel aggradation followed by incision and entrenchment on the Waimakariri River in New Zealand following increased sediment inputs from bank

erosion. Beschta (1984) documented channel widening followed by subsequent narrowing as a consequence of increased soil erosion from logging activities. Roberts and Church (1986) documented channel incision, and fining of the bed material in an aggraded channel following increased sediment inputs from timber harvest. Madej and Ozaki (1996) analyzed changes in channel cross-sectional geometry, and documented channel aggradation, subsequent degradation, and channel widening following increased sediment supply due to poor land use practices. They also noted that the roughness of the channel increased with an increase in the topographic complexity of the bed. Following several debris flow sediment inputs, Miller and Benda (2000) observed channel widening and braiding, fining of bed material followed by coarsening, construction of coarse grained terraces, and formation of new side channels. After the sediment wave had passed, they observed channel incision down to an immobile bed and bedrock. Cui et al. (2003) conducted flume experiments to investigate sediment pulses, found that in a channel with alternate bars, the bed relief decreased with the arrival of the downstream edge of the sediment wave and increased as the upstream edge of the wave passed.

The majority of the sediment transported through the fluvial system is generated through hillslope erosion in the headwater reaches (Schumm, 1977). The rates at which these headwater channels deliver sediment to downstream reaches affects the building and modification of alluvial landforms far downstream of the episodic events that deliver sediment to the channel. Channel depositional processes such as the construction of bars, floodplains and deltas are strongly dependent on sediment supply. A large increase in sediment supply to channels with established floodplains can lead to floodplain aggradation and terrace construction (Miller and Benda, 2000). Understanding how

headwater channels process sediment pulses will help in understanding how sediment is routed through a channel network, helping predict any possible damage to infrastructure downstream and may assist in predicting the fate of sediment released from dam removal projects (Sutherland et al., 2002).

Large sediment inputs to stream channels affect associated riparian and aquatic ecosystems. Some riparian floodplain plant species are dependent on the overbank deposition of fine sediments for propagation, whereas deposition of fine sediments in salmonid spawning areas can significantly reduce spawning success (Carnefix, 2002). Benda et al. (2003) found that debris flow fans deposited in channels increase the physical heterogeneity of the channel. This increase in channel heterogeneity has implications for riverine ecology because physical heterogeneity is a vital part of maintaining aquatic and riparian biodiversity and productivity (Benda et al., 2003).

Debris flows and landslides can deliver large amounts of large woody debris (LWD) and Miller and Benda (2000) documented channel log jams associated with debris flow deposits. Benda et al. (2003) found that up to 80% of the wood in low-order channels in Washington's Olympic mountains was delivered with debris flows. Previous studies have documented pool formation associated with in-channel LWD (Montgomery et al., 1995; Beechie and Sibley, 1997). Benda et al. (2003) found a correlation between LWD and pools in channels with debris flow sediment inputs, where the number of pools was proportional to the amount of LWD. The presence of pools formed by LWD has implications for fish habitat Carnefix (2002) found that bull trout (*Salvelinus confluentus*) use LWD-formed pools 80% of the time and documented increased spawning recruitment to channels with these types of habitats.

The delivery of a large pulse of sediment can affect the sediment transport rate of a channel. Cui and Parker (2003) found through flume experiments that “the introduction of a sediment pulse into an otherwise equilibrium system reduces the sediment transport rate upstream of the pulse significantly.” This result is in agreement with the observations of Sutherland et al. (2002), who documented a similar response upstream of a sediment pulse on the Navarro River. Downstream of a pulse, however, large sediment inputs have been linked to two mechanisms that can increase sediment transport rates. First, a local increase in slope at the downstream edge of a sediment pulse increases the tractive force acting on the bed and increases sediment transport capacity (Cui and Parker, 2003; Lisle et al., 1997). Second, Cui and Parker (2003) documented that the addition of a pulse of fine sediment to a coarse armored channel increased the sediment transport rate and greatly increased the mobility of the coarse material, often destroying the armored surface layer. Wilcock (1998) described a similar increase in sediment transport rate with the addition of fine material to a coarse bed.

Punctuated sediment delivery often produce “pulses” or “waves,” defined as transient areas of sediment aggradation in channels, created by large sediment inputs (Lisle et al., 2001). Theoretical, experimental, and field studies have investigated the behavior of sediment waves and the processes responsible for wave translation or dispersion. Wave-like behavior of sediment pulses was first described in Gilbert’s (1917) seminal paper on sediment waves of placer mining debris in tributaries of California’s Sacramento and American Rivers. He documented translation of a discrete sediment wave with the apex of the wave moving “like a great body of storm water” in the downstream direction. Numerous studies have documented a similar translational

behavior in sediment waves (Griffiths, 1979; Pickup et al., 1983; Meade, 1985; Turner, 1995; Madej and Ozaki, 1996; Miller and Benda, 2000). However, other studies of sediment waves in natural rivers and experimental flumes show a dispersion dominated behavior (Roberts and Church, 1986; Knighton, 1989; Lisle et al., 1997; Dodd, 1998; Lisle et al., 2001; Cui et al., 2001).

STUDY SITE

Sleeping Child Creek (SCC) is a tributary of the Bitterroot River located in the Sapphire Mountains of west-central Montana (Figure 1). The upper portion of the basin is steep, forested terrain typical of Northern Rockies mountain topography. Mixed coniferous forests of Douglas fir (*Pseudotsuga menzeiesii*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), and sub-alpine fir (*Abies lasiocarpa*) dominate. Understory species consist of ninebark (*Physocarpus malveceus*), snowberry (*Symphoricarpos albus*), Oregon grape (*Berberis repens*), and native bunchgrasses. The lower portion of Sleeping Child Creek winds through relatively low-gradient agricultural lands and the Bitterroot River floodplain.

The climate is semi-arid montane with warm dry summers and mild winters (Hyde, 2003). The average annual precipitation is 79 cm/yr, characterized by snowfall from November to March, and May and June being the wettest months. Sleeping Child Creek drains 169 km², with a mean basin elevation of 1900 m. Streamflow is snowmelt-dominated with an annual peak during spring runoff, and occasional winter peaks from rain-on-snow events. Bankfull discharge in the study reach is estimated to be 12.8 m³/sec. Gniess and granite comprise the dominant lithology of the study area (Hyde, 2003). Soils are thin, poorly developed sandy to silty loams with a significant fraction of coarse material.

Approximately 15 km² of the upper basin experienced a severe forest fire in August of 2000 (Hyde, 2003). High-intensity convective storms triggered numerous debris flows in the burned areas in July 2001. Ten debris flows deposited fans on the valley floor in the study area. The debris flow fans are comprised of a mix of coarse

sand, gravel, and large cobbles/boulders. Hyde (2003) reported an additional 6 debris flows fans in the channel upstream of the study reach.

The 10 kilometer study reach of SCC is located in the middle portion of the watershed (Figure 1). The third-order channel is confined by steep valley walls with numerous bedrock outcrops and the active floodplain width varies between 20 to 130 meters. In reaches not affected by the sediment pulses, channel width is 10-30 meters with channel gradients between 2 and 7%. Unaffected study reaches have armored beds of coarse cobble and boulders inset with large lag deposits ($150\text{mm} < D_{50} < 300\text{mm}$), channel morphology is best described by Montgomery and Buffington's (1997) classification as boulder-cascade and step-pool. Streambanks are stable and comprised of boulder, cobbles and fine alluvium that is well-vegetated with a mix of riparian species. Streambank erosion does not appear to be a large source of sediment to the channel.

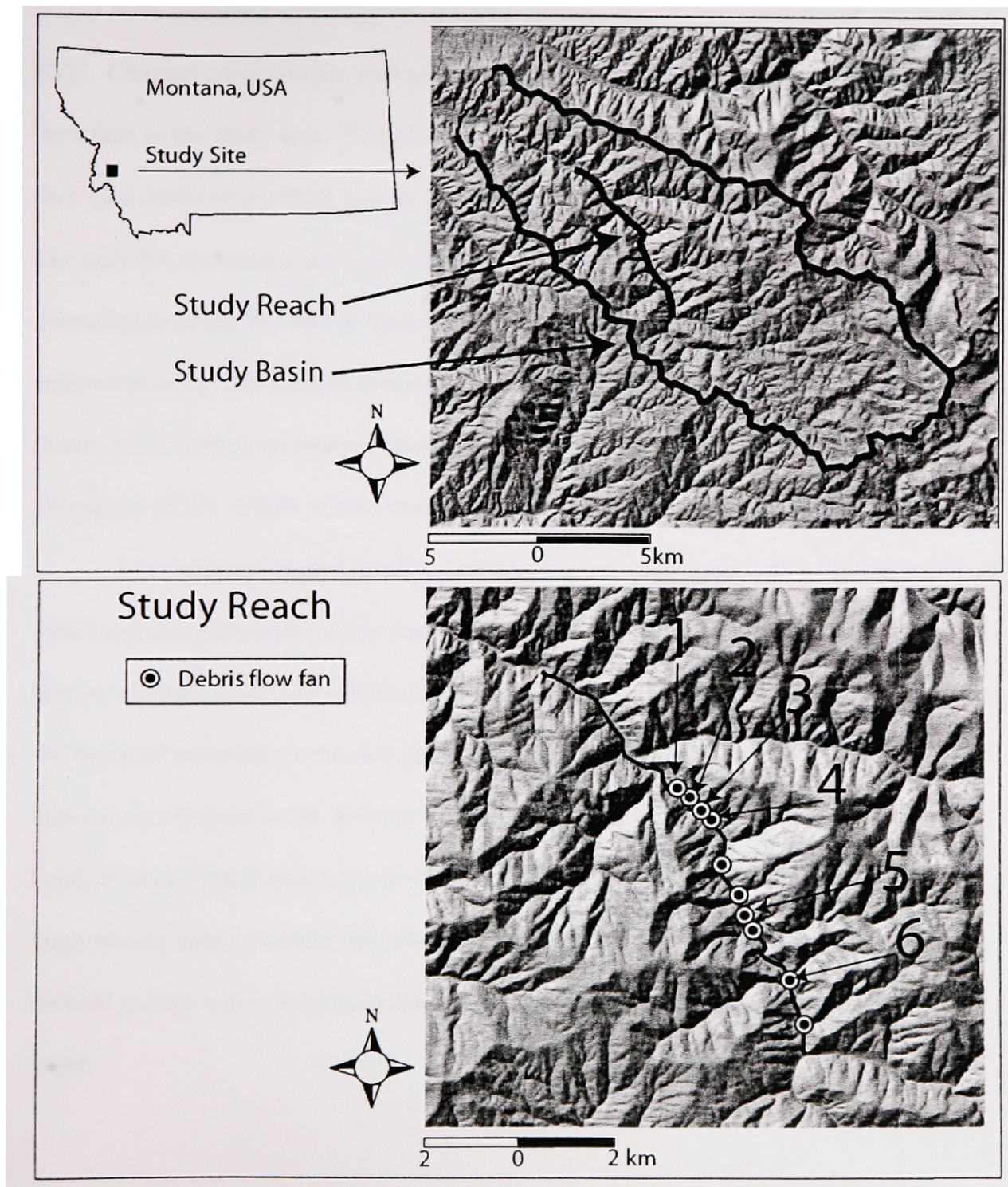


Figure 1. Map of study site.

METHODS

Eighteen channel cross sections, along with twenty-three water surface and bed slopes were surveyed with a surveyor's level or hand level on a 10 kilometer reach of SCC. Channel cross section locations were organized with respect to six of the ten debris flow fans in the study area. The longitudinal profile (Figure 2) identifies all ten debris flow fans in the study reach and the six fans associated with the cross section surveys. For each fan, a cross section was located 10-30 meters upstream of the fan, 10-30 meters downstream of the fan, and in the middle of the reach cutting through the fan. These are referred to as up-fan reaches, down-fan reaches and fan reaches, respectively (Figure 3). Grain size distributions were estimated at each cross section with pebble counts (Wolman, 1954). Clasts <2mm were grouped together as were those >520mm.

Residual pool depths, lengths, and spacing were surveyed with a hip chain and stadia rod along the entire study reach. To be classified as a pool, a channel unit had to display obvious scour and a downstream crest. Residual pool depths were calculated as the depth of water below the elevation of the downstream riffle crest (Lisle, 1987). Pool spacing was defined as the distance between the downstream crest of one pool and the head, or beginning of scour, of the closest downstream pool. Occurrence and number of large woody debris was also recorded in the channel survey. Large woody debris was defined as logs with a minimum diameter of 25 cm and a length greater than the channel width.

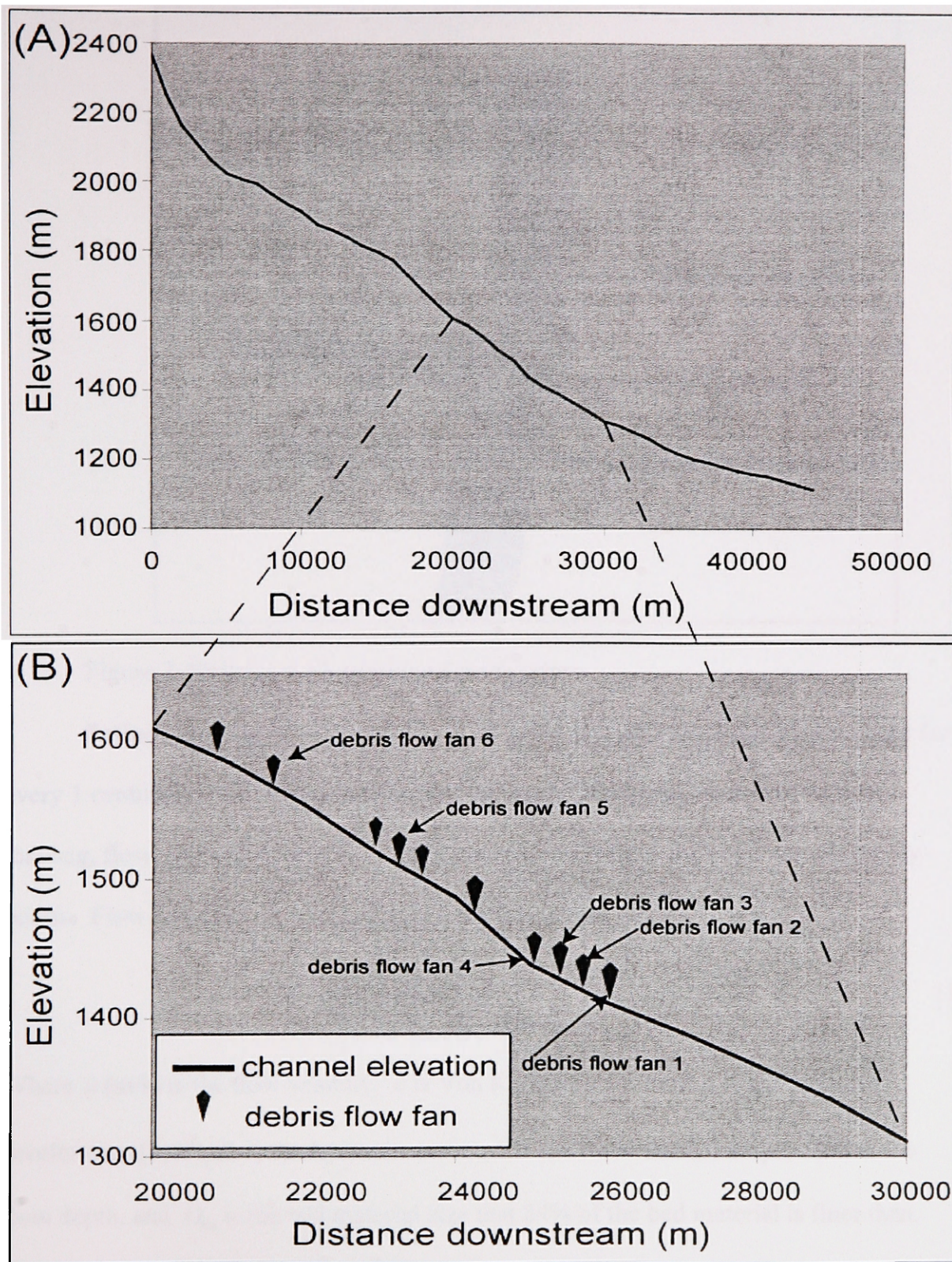


Figure 2. (A) Longitudinal profile of Sleeping Child Creek.
(B) Location of debris flow fans in the study reach.

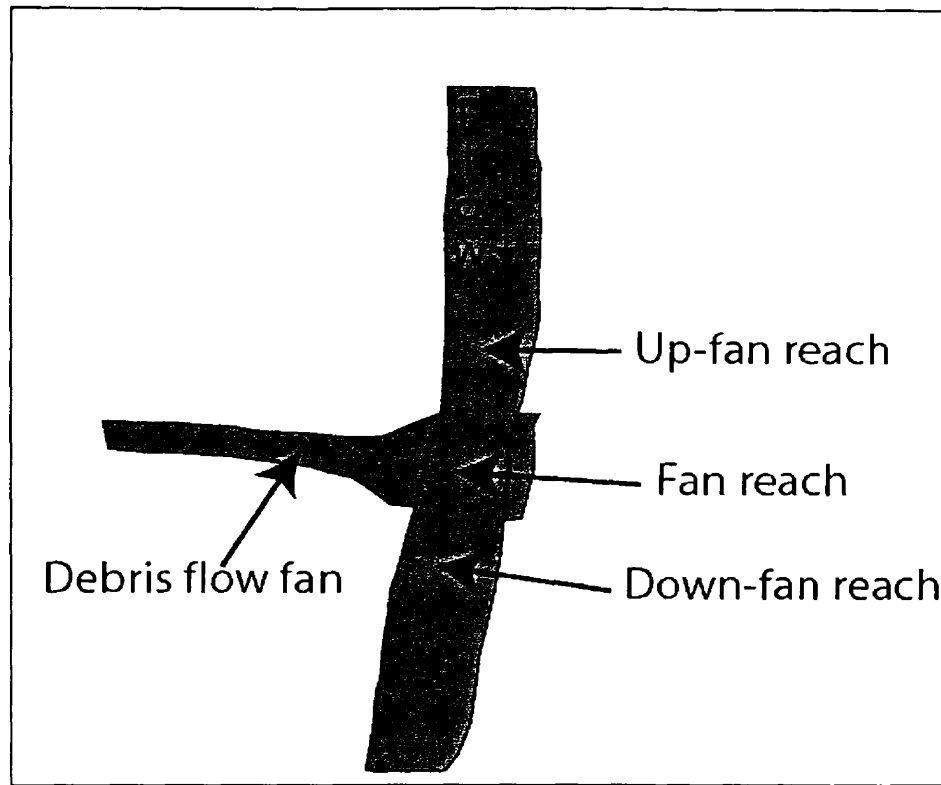


Figure 3. Definition illustration of reach types.

Rating curves were developed for each cross section by calculating discharge for every 1 centimeter increase in flow depth. For each flow depth, measured from the thalweg, flow area and hydraulic radius were calculated from the cross section survey points. Flow velocity was estimated with the Law of the Wall

$$u = \frac{1}{\kappa} \sqrt{gRS} \ln 3.14 \frac{h}{D_{84}} \quad (1)$$

Where u (m/s) is the flow velocity, κ is Von Karman's constant, g is gravitational acceleration (m/s^2), R is the hydraulic radius, S is the water surface slope, h (m) is the flow depth, and D_{84} is the bed material size that 84% of the bed material is finer than.

Discharge was then calculated with the continuity equation

$$Q = whu \quad (2)$$

Where w (m) is the flow width. Width/depth ratios at bankfull discharge were calculated from the survey points for every cross section. Bankfull discharge was estimated from a flood frequency plot as the flood with an annual exceedance probability of 50%.

Although the 1-2 year flood may not be the bankfull discharge for this type of channel, due to the coarse nature of the bed and bank material we were unable to estimate bankfull discharge from morphologic bankfull indicators.

RESULTS

Visual observation indicates that the channels were pinned against the valley wall and dammed by the debris flow fans. The flow then overtopped the fans and started to incise through them. These fan reaches have coarse bed material and are entrenched. Channel braiding and the construction of numerous gravel bars was observed in channels immediately downstream of the debris flow fans. Large scale aggradation of coarse sand and fine gravel was observed in the up-fan reaches and, in some reaches this deposition is valley-wide and 1-2 meters deep. Recent channel displacement has been observed in up-fan, fan, and down-fan reaches and is obvious from the presence of trees in the middle of the channel.

Channel Geometry and Width/Depth Ratios

High width/depth ratios can be indicative of aggraded reaches and low width/depth ratios suggest an incised or entrenched channel (Miller and Benda, 2000). Several previous studies have documented aggradation followed by incision in channels with a sediment pulse or wave (Gilbert, 1917; Griffiths, 1979; Roberts and Church, 1986). Width/depth ratios in up-fan channels 1,2,3, and 6 ranged from 72-170 (Figure 4). Figure 4 shows the high width/depth ratios in up-fan channels, relative to fan channels, suggesting that these reaches are aggrading. This agrees with observations of trapping of bed load material behind some of the debris flow fans. The process responsible for this channel widening is not bank erosion, the channel has aggraded to a point where the old channel and banks are completely buried by 1-2 meters of sand. This is evident when excavating sand from around the trunks of standing trees in the floodplain: branches can be found at a depth of over 1 meter below the surface,

demonstrating recent deposition. The width/depth ratios in fan channels 1,2,3,5, and 6 range from 12-37, these low values suggest that these reaches are incising and are moderately entrenched (Figure 4). The reaches associated with debris flow 4 and the up-fan channel of debris flow 5 have a channel geometry that is bedrock-controlled and do not reflect the processes described above.

The width/depth ratios in down-fan channels 1,2,3,5 and 6 range from 22-147. In these downstream reaches, deposition of coarse fan material has aggraded the channel up to the adjacent floodplain elevation resulting in braiding and the formation of side channels in what was previously riparian forest. The presence of gravel and cobble bars suggests a depositional environment where the channel is overwhelmed with coarse bedload. Braiding is typical in channels transporting large amounts of bedload and with a high coarse sediment supply (Bridge, 2003). Other workers have documented channel braiding in aggrading reaches following a sediment pulse, including Miller and Benda (2000), on Gate Creek in Oregon, Madej and Ozaki (1996), on California's Redwood Creek, and Roberts and Church (1986), in British Columbia.

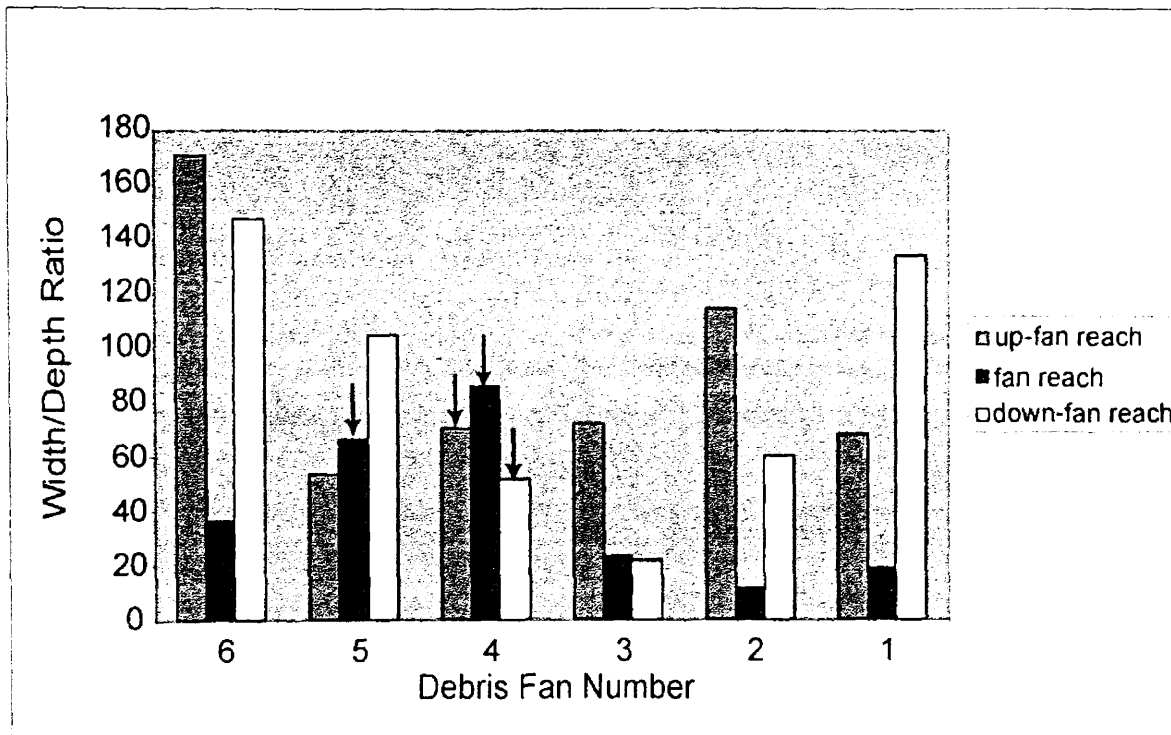


Figure 4. Channel width/depth ratios show a pattern of deposition in up-fan channels, incision in fan channels and braiding in down-fan channels. Channels marked with an arrow are bedrock-controlled, explaining, perhaps, why they do not exhibit a pattern similar to the others. The down-fan channel of debris flow 3 did not braid, possibly because debris flow 3 deposited the least amount of sediment on the valley floor.

Channel Gradient

Changes in channel geometry and morphology are often associated with adjustments in channel gradient (Montgomery and Buffington, 1997). A repeating pattern of gradient changes over a short distance due to debris flow fans has been observed on Sleeping Child Creek (Figure 5). Up-fan channel gradients range from 0.007-0.038, fan channel gradients range from 0.021-0.072, and down-fan channels gradient range from 0.017-0.047. The increase in channel gradient at the transition from up-fan reaches to fan reaches is often great. For example, the reach associated with debris flow fan 6 increases by a factor of 7 (0.009-0.067) over a distance of 10 meters. It is important to differentiate between the processes responsible for these gradient changes. The decrease in channel gradient upstream of the debris flow fans is due to the sudden

change in valley slope that accompanied the deposition of a debris flow fan. The reaches cutting through debris flow fans are steep because the channel, as it dropped off the downstream edge of the debris fan, created a headcut that propagated upstream through the easily erodable fan material. Below the fans, the braided reach is adjusting its gradient to the supply and size of the sediment being delivered to it as bedload from the fan. The braided reach may be as steep or steeper than the fan reach because of the sediment supply and character, the greater the sediment size and supply the steeper the reach (Hack, 1957).

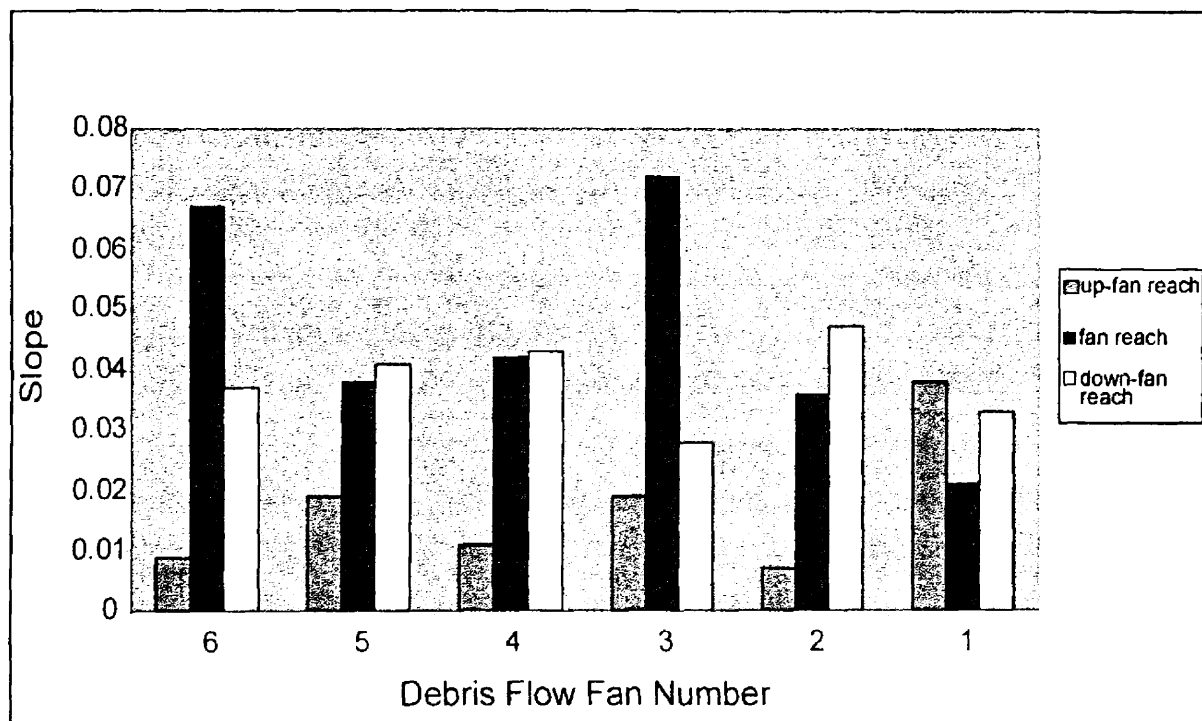


Figure 5. Channel slopes generally show a pattern of low slopes upstream of debris flow fans and steeper slopes in fan reaches and downstream reaches. The up-fan reach of debris flow fan 1 does not exhibit a similar pattern to the others, possibly because the fan was deposited at the downstream edge of a locally steep reach.

Bed Material Size

Earlier studies of sediment pulses have documented a fining of bed material subsequently followed by a coarsening (Meade, 1985; Roberts and Church, 1986; Miller and Benda, 2000). Finer bed material was observed in the aggrading reaches upstream of debris flow fans than in the incising reaches through the fans and the braided reaches downstream of the fans (Figure 6). Median bed material size (D_{50}) in up-fan reaches ranges from 2-104 mm, fan reaches range from 105-192 mm, and down-fan reaches range from 93-222 mm. Sampling fan reaches was often difficult due to the high flow depths and the degree of bed material imbrication in these reaches. The change in grain size between reach types is often large, the up-fan reach of debris flow 6 has a $D_{50} < 2$ mm while the fan reach just downstream has a D_{50} of 146 mm, an increase of two orders of magnitude over 7 meters. This supports the assertion that some of the debris fans are functioning as bedload traps with large-scale deposition of well-sorted bedload material. The bed material in fan and down-fan reaches is a mobile pavement of coarse gravel and cobbles with a fraction of immobile boulders. As the channel cuts through the fan, the fine fraction of the fan material is winnowed out, leaving the coarse pavement; during high flows this coarse material may be entrained and transported as bedload.

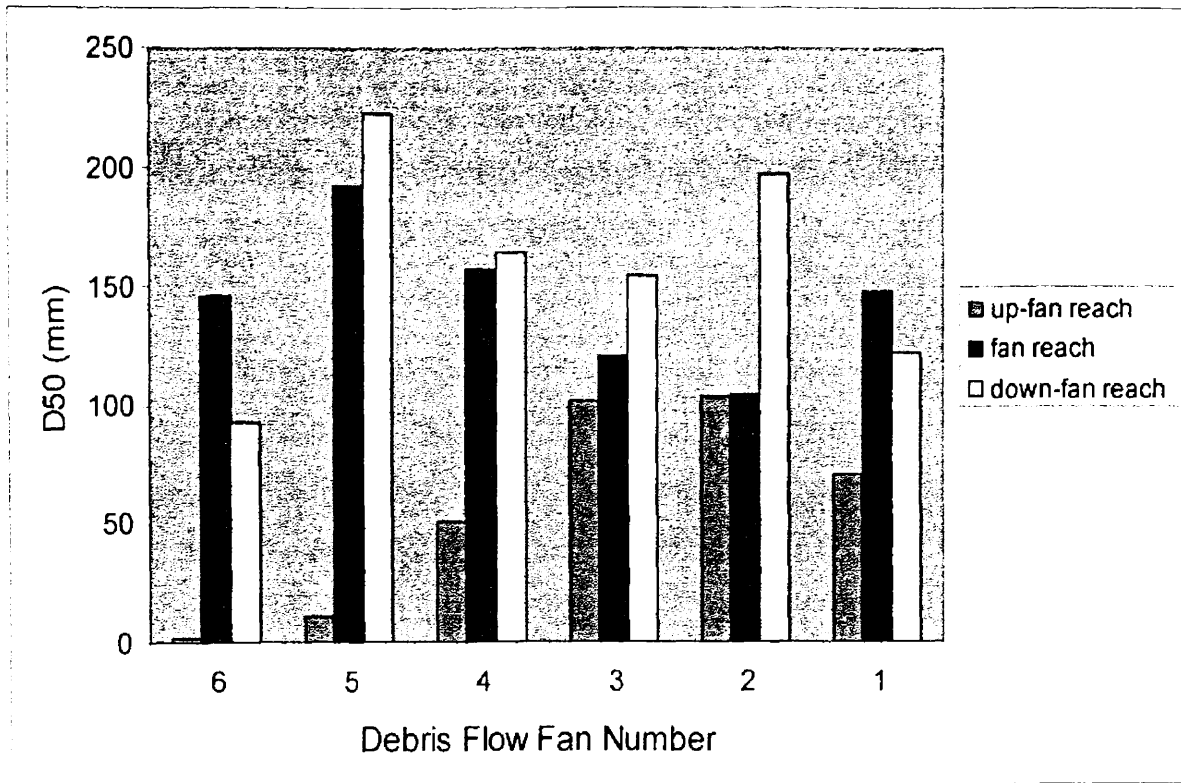


Figure 6. Median bed material size (D_{50}) follows a pattern where up-fan reaches are finer than down-fan and fan channel reaches.

Spatial Distribution of Large Woody Debris

Large amounts of LWD have been delivered to the channel of SCC by the debris flows and aggregates of LWD have accumulated in the fan reaches and down-fan reaches. A survey was conducted on the entire study reach to record the presence and amount of LWD in the channel. Figure 7 illustrates the large amount of LWD in close proximity to debris flow fans.

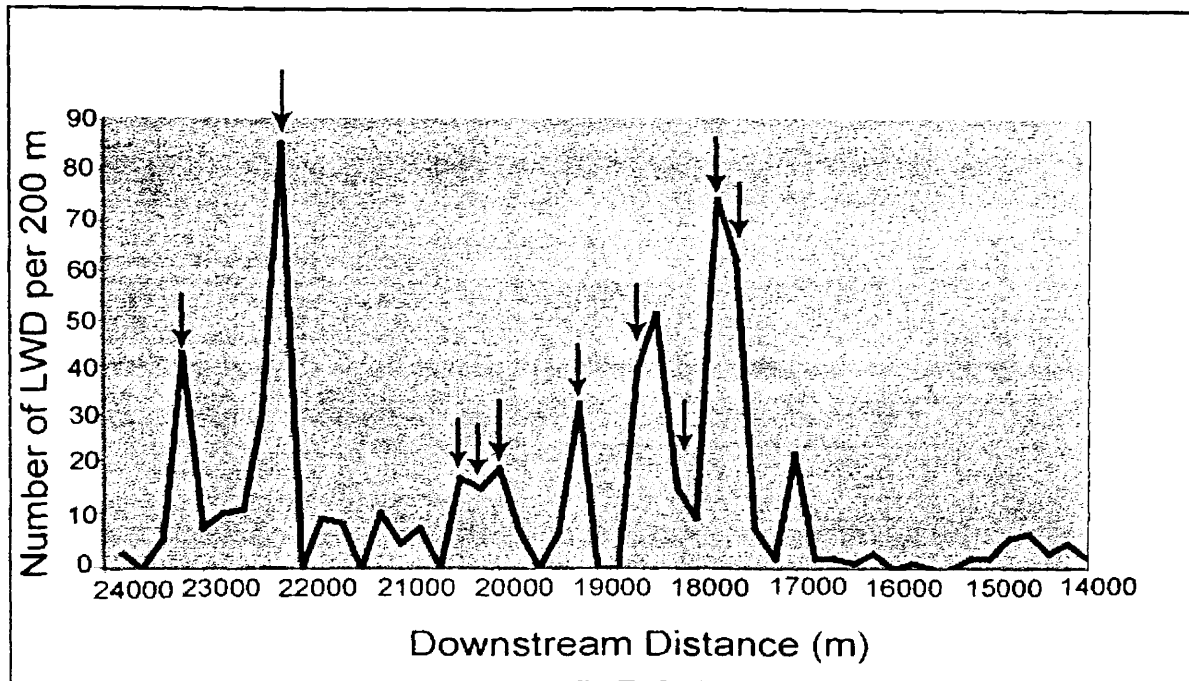


Figure 7. The spatial distribution of LWD. Arrows identify the location of debris flow fans. The pattern of high amounts of LWD in close proximity to debris flow fans supports observations of LWD being delivered to the channel with debris flows. Note the relative absence of LWD in the 3 kilometer reach below the fans (14,000 – 17,000 m).

Pool depths and frequency

Residual pool depths have been used by Madej and Ozaki (1996) to signal the arrival of a sediment wave, to calculate sediment wave transit rates, and as an indicator of channel recovery. Residual pool depths were measured for every pool in the 10-kilometer study reach. Residual pool depths were spatially averaged by calculating the mean residual depth of every pool in 50 meter increments downstream of debris flow fans. The results show that pool depths decrease with downstream proximity to a debris flow fan (Figure 8), supporting the idea that pools aggrade with sediment after the introduction of a sediment pulse.

Pool spacing was averaged over nine reaches, with each reach beginning at a debris flow fan. The mean distance between pools is plotted against the number of the

pool downstream from the point of sediment entry with pool number 1 being the closest downstream pool to the debris flow fan (Figure 9). Pool spacing increases with proximity to a debris flow fan, suggesting that pools are aggrading to a point where they are no longer recognizable.

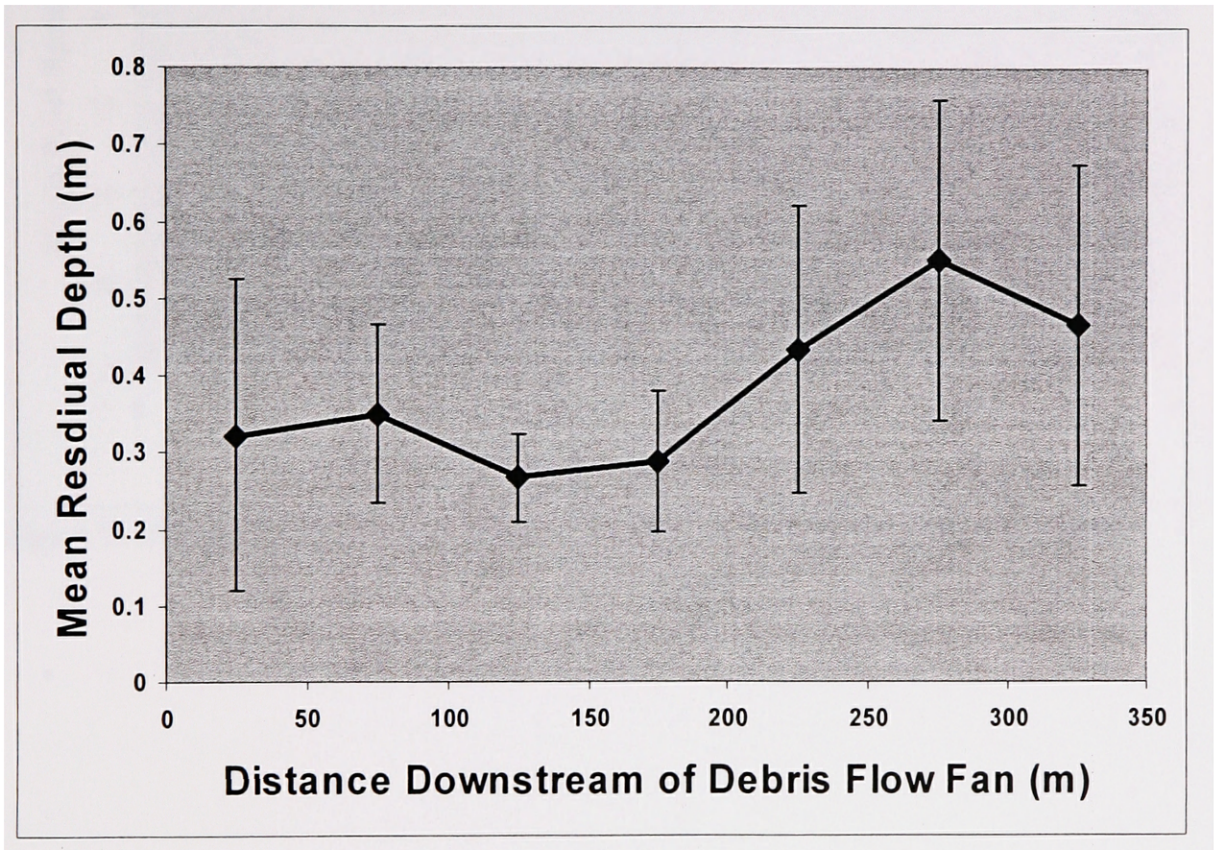


Figure 8. The spatial distribution of spatially averaged pool residual depths demonstrates that pool depths decrease with downstream proximity to debris flow fans.

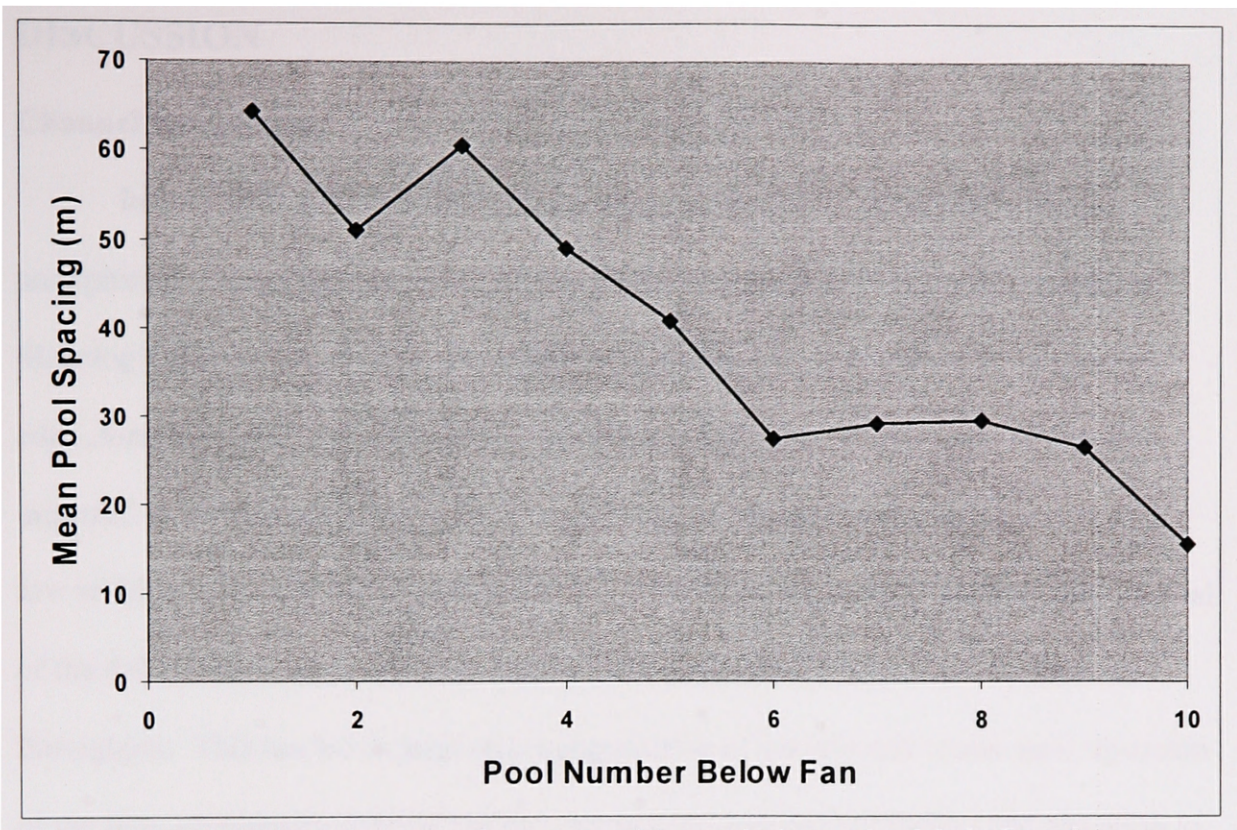


Figure 9. The mean pool spacing increases with proximity to the debris flow fans.

DISCUSSION

Channel Morphology

In July 2001 post-fire debris flows triggered by intense convective storm precipitation deposited fans of mixed fine and coarse sediment across the channel of Sleeping Child Creek. The flow overtopped each fan and dropped off its downslope edge, forming a headcut in the easily erodible fan material. The headcut eventually migrated to the upslope edge of each fan leaving an incised, entrenched channel with a low width/depth ratio and inset between 1-2 meter high terraces of fan material. Several of the debris flow fans function as channel sediment traps, with little to no bedload throughput. This has led to large-scale aggradation of gravels and coarse sand upstream of the fans, completely burying the old channel and raising the channel bed elevation to, or above, the adjacent floodplain. The obvious source of the sediment is the closest upstream debris flow fan. As the channel aggraded and flow began to spill onto the floodplain during high discharges, overbank deposition of sediment on the floodplain led to the construction of a new floodplain, at a higher elevation and comprised almost completely of coarse sand. The riparian forest occupying the floodplain is dying, probably as a result of being buried by 1-2 meters of sediment. As the channel downcuts through the fan, the easily transported fine sediment (sand and small gravel) is flushed downstream to the closest downstream fan where it becomes trapped. The coarse fraction of the fan is transported as bedload much shorter distances and deposited in reaches directly downstream of debris flow fans. As the channel transitions from fan reaches to down-fan reaches, the channel width/depth ratio increases and it loses sediment transport capacity. The channel drops some of its bedload and braids into multiple channels,

separated by coarse gravel and cobble bars, and bars formed from sediment wedges building upstream of LWD delivered with the debris flows.

Model of Channel Response

From the data, a repeating pattern of slopes, sediment size, width/depth ratios, sediment deposition, channel incision and sediment transport has been identified and the following is a model of channel response to a large sediment delivery event (Figures 10, 11). Up-fan channels are typically single-thread with lower slopes and finer bed material size than the other channel reaches. These channels are aggrading and exhibit high width/depth ratios. Fan reaches are, in general, incised and entrenched single thread channels with steep slopes and coarse bed material. They are often in a state of active downcutting and progressive armoring. Down-fan reaches are typically braided, with high width/depth ratios, steep slopes and coarse bed material. These reaches are aggrading and display numerous cobble and gravel bars.

The debris flows have deposited large amounts of LWD on the valley floor and in the channel. LWD jams are common in the braided reaches of SCC and are the loci of aggradation; this observation is in agreement with the work of Keller and Swanson (1979). LWD can play a significant role in pool formation, fish habitat and bank erosion (Keller and Tally, 1979; Carnefix, 2002). Debris flows appear to be a significant mechanism for LWD recruitment on SCC.

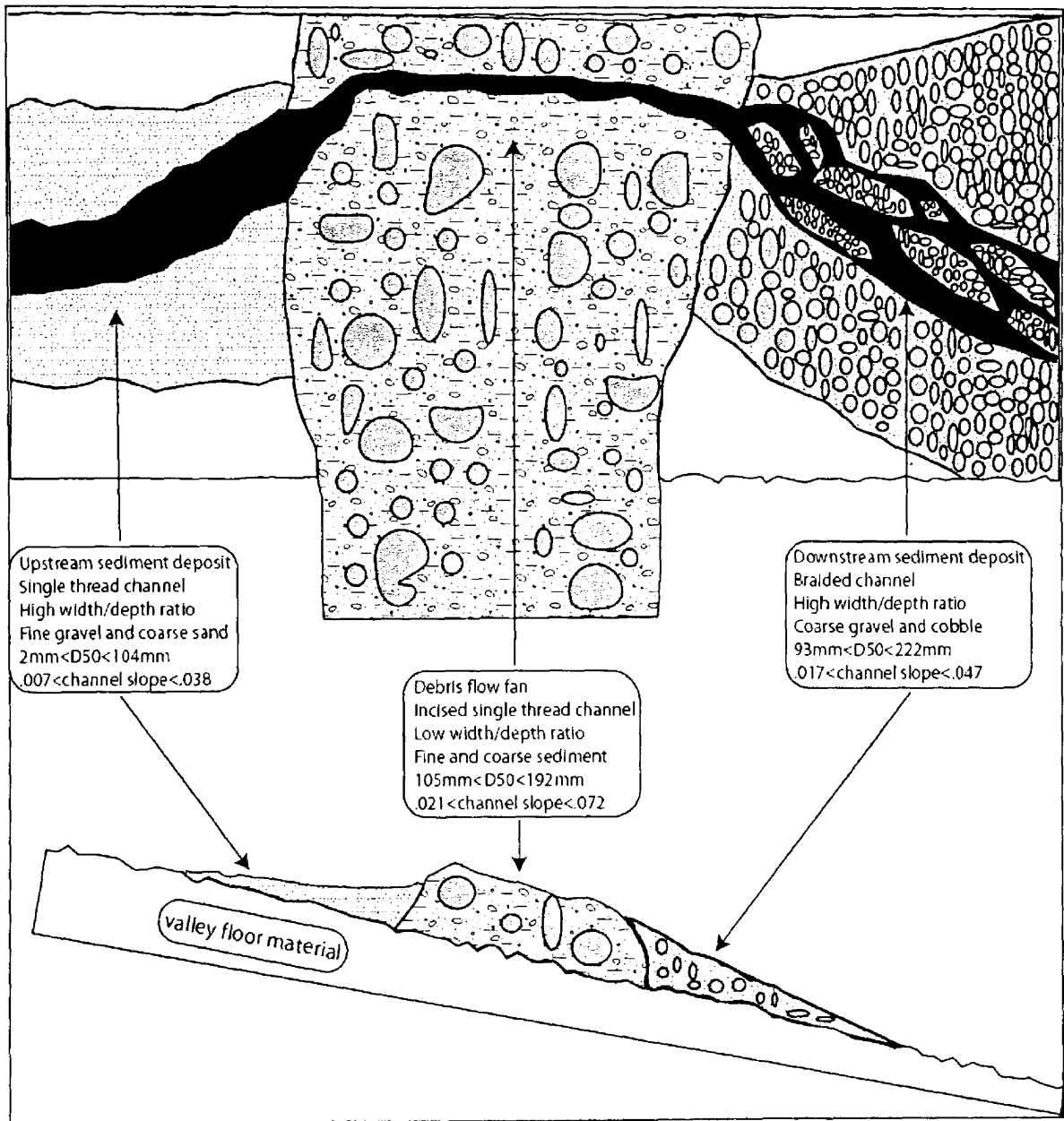


Figure 10. Typical pattern of channel response to a sudden increase in sediment supply.

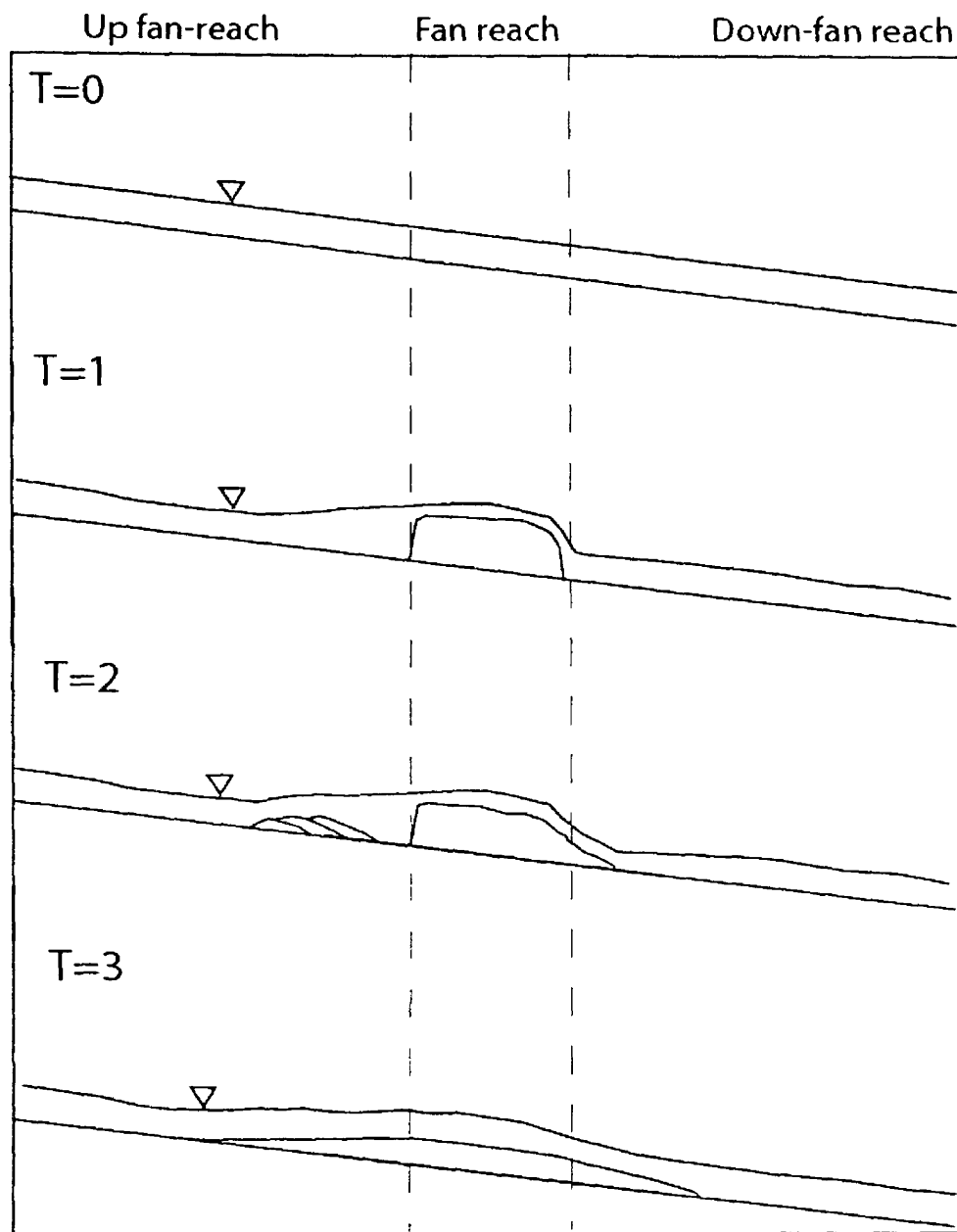


Figure 11: Time series of typical channel profiles

Sediment Transport

Sleeping Child Creek is transporting debris flow fan material under conditions of size-selective transport. Coarse sand is winnowed out of the fan and transported as suspended load. Sand has been deposited on channel margins, behind obstructions such as LWD, boulders or other velocity shelters, on the active floodplain during overbank flows, and upstream of debris flow fans. The volume of sand stored upstream of debris

flow fans is great, in some instances filling a 100 meter wide valley floor with 1-2 meters of sediment for several hundred meters upstream. The volume of sand stored in the active channel is also great, channel obstructions have created areas of sand deposition that, while small, are numerous, and channel margins display thin (1mm-100mm) sand lenses that continue uninterrupted through most of the study reach.

The influence of sand on the mobility of a coarse bed has been investigated experimentally (Wiberg and Smith, 1987; Wilcock, 1998; Cui et.al., 2003). The presence of a fine fraction increases the mobility of the coarse fraction by reducing the pocket angle or grain pivot angle and by reducing the form drag associated with individual clasts (Wiberg and Smith, 1987; Wilcock, 1998). We have not attempted to quantify the effect of the addition of large amounts of sand on the mobility of the coarse bed material in Sleeping Child Creek but visual observations of reaches where sand has filled all the interstitial space in a predominantly coarse bed suggests that the addition of sand from debris flow fans has led to increased bedload transport of coarse bed material.

Gravels and cobbles are transported as bedload much shorter distances and deposited in downstream tapering wedges from debris flow fans and this sediment is filling in pools and reducing bed relief (Figures 8, 9). The reduction in bed relief should result in a decrease in the form drag or bed form resistance. As the form drag of a channel decreases, the portion of the total boundary shear stress acting on the grains in the boundary increases, thereby increasing the channel's capacity to transport sediment (Meyer-Peter and Muller, 1948). Although it was not possible to make actual measurements of bedload transport rates and volumes, it can be shown that, theoretically, the measured change in bed topography (e.g., pool depths and spacing) should result in a

decrease in form drag and an associated increase in sediment transport (Meyer-Peter and Muller, 1948).

Other workers have observed reductions in bed relief associated with sediment pulses similar to those measured at SCC. Meade (1985) described the migration of bedload waves and documented, that with the arrival of a wave, the pools filled in with sediment. In severely disturbed watersheds in British Columbia, Roberts and Church (1986) describe a decrease in channel complexity in aggraded reaches following a sediment wave. Madej and Ozaki (1996) investigated the effects of a sediment wave on Redwood Creek, California, and documented a decrease in pool depths and an increase in pool spacing. Madej (1999) reported that the variation in bed elevation is low immediately following a sediment input and increases with time. Madej (2001) further documented that as channels recovered from the passage of a sediment wave, bed topography complexity increased, pool spacing decreased, and flow depths increased. Smith et al. (2002) observed from field and laboratory flume investigations that sediment waves produced plane beds with little bed complexity.

Robert (1990) examined numerous studies of channel roughness and found that using the depth-slope product to estimate boundary shear stress (Equation 4) in bedload transport studies was inadequate in channels where grain resistance does not approximate total resistance. In other words, form drag must be taken into effect to properly describe sediment transport. Colby (1964) working in sand channels, found the sediment transport rate in a plane-bed channel to be close to an order of magnitude greater than a channel with bedforms (dunes) at the same value of boundary shear stress. Carson (1987) found that one of the major difficulties with using a tractive-stress approach to predicting

bedload transport rates was evaluating the effect of bed form resistance on sediment transport. Meyer-Peter and Muller (1948) documented the effects of form drag on sediment transport while developing a bedload transport function. They found that their first attempts to estimate bedload transport rates overestimated transport in channels with significant bed topography.

Scenarios of Continued Response

The amount of time needed for Sleeping Child Creek to recover to some equilibrium state is partially controlled by the channel reaches that cut through the debris flow fans. These coarse, armored channels act as a local base-level control. As these reaches continue to downcut through the debris flow fan, their bed material armors and new boulder lag is exposed in the bed or deposited in the channel from its unstable banks. The channel will stop downcutting if the bed material becomes too coarse, or the channel reaches an elevation where a balance is reached between sediment deposited in and transported out of the reach. If the former occurs, the reach upstream of the fan will continue to aggrade until the accommodation space is filled and it no longer traps bedload and bedload throughput becomes possible. If the latter condition is reached the up-fan may downcut through the fine material deposited there and form a set of fine grained terraces.

CONCLUSION

The supply of sediment to the fluvial network in mountain drainage basins is episodic with large infrequent landslides and debris flows contributing large sediment influxes. Identifying the processes of sediment pulse dispersal provides insight into the development of mountain landscapes. A series of post-fire debris flows deposited fans of mixed fine and coarse sediment into Sleeping Child Creek and pinned it against the valley wall. The channel incised through the fans, creating a set of coarse grained terraces. The upstream edge of the fans act as bedload traps, creating longitudinal discontinuities in sediment transport and causing large-scale aggradation of fine sediment. This aggradation has raised the bed elevation and created new floodplains. Reaches downstream of the fans widened and braided. Overall, channel bed material became finer with great spatial variation in median bed material size. A conceptual model of channel response was presented along with data and observations supporting it.

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APPENDIX A

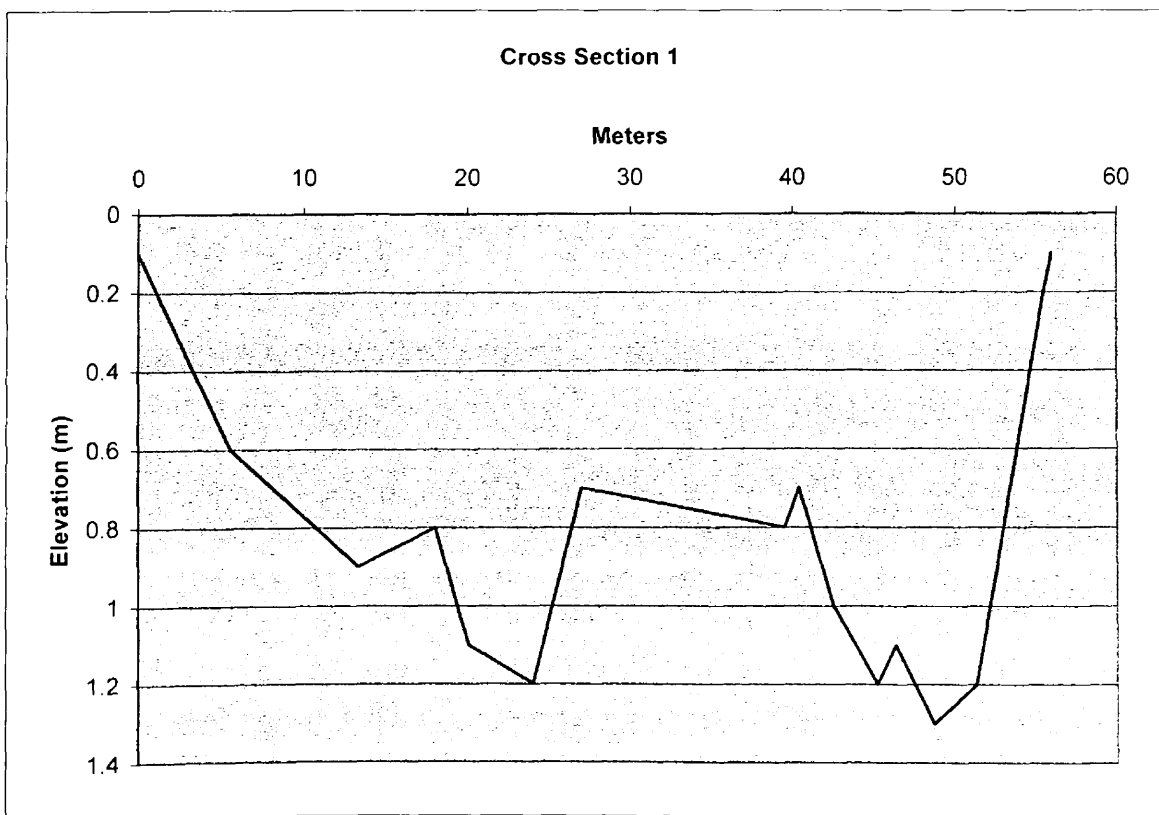
CHANNEL CROSS SECTION SURVEYS

Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	up-fan reach of 6th DBF
Downstream distance	1630m
Cross Section Number	1
Notes	surveyed with hand level

X (m)	Y (m)	
0	0.1	
5.6	0.6	
13.3	0.9	
18	0.8	
20	1.1	
24	1.2	
27	0.7	
39.5	0.8	
40.4	0.7	
42.5	1	REW
45.2	1.2	
46.3	1.1	
48.7	1.3	thalweg
51.3	1.2	LEW
55.5	0.2	
56	0.1	

REW = right edge water

LEW = left edge water

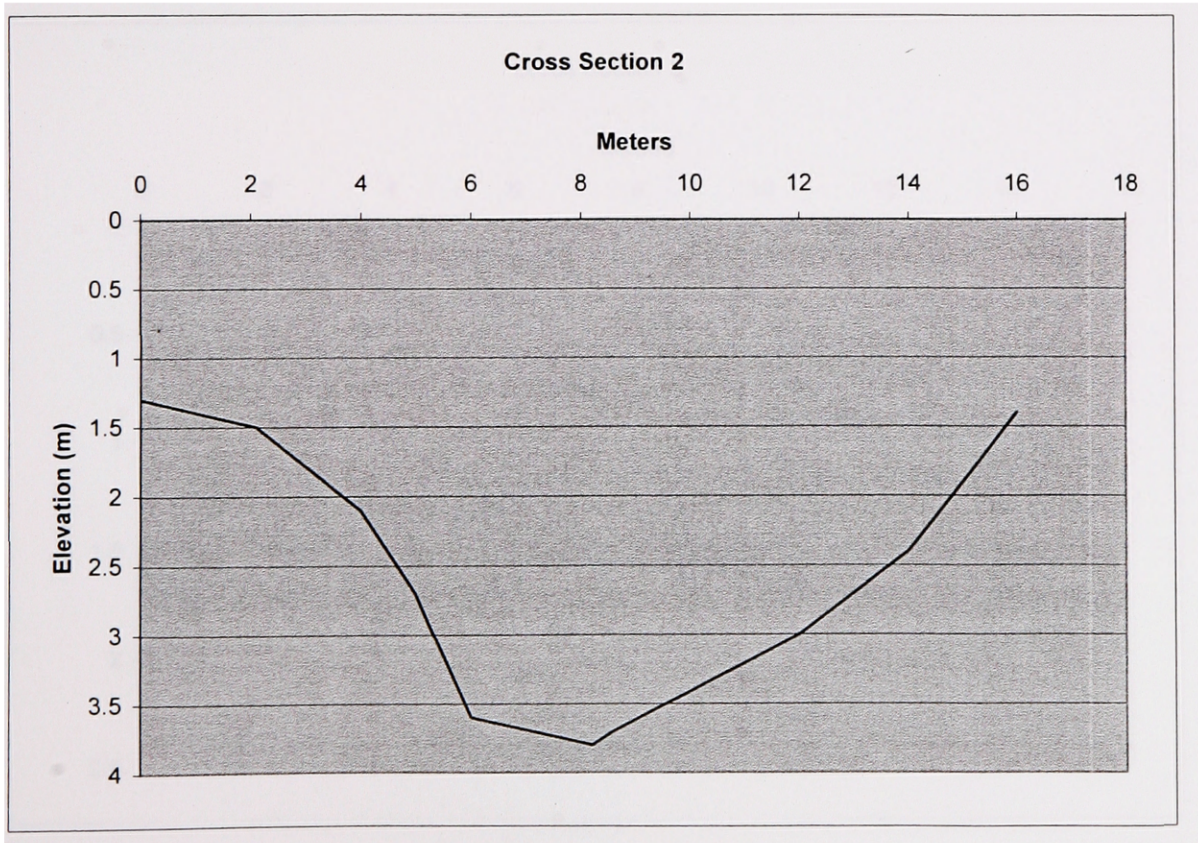


Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	Fan reach of 6th DBF
Downstream distance	1660m
Cross Section Number	2
Notes	surveyed with hand level

X (m)	Y (m)	
0	1.3	
2.1	1.5	
4	2.1	
5	2.7	
6	3.6	REW
8.2	3.8	
8.6	3.7	thalweg
12	3	
14	2.4	LEW
16	1.4	

REW = right edge water

LEW = left edge water

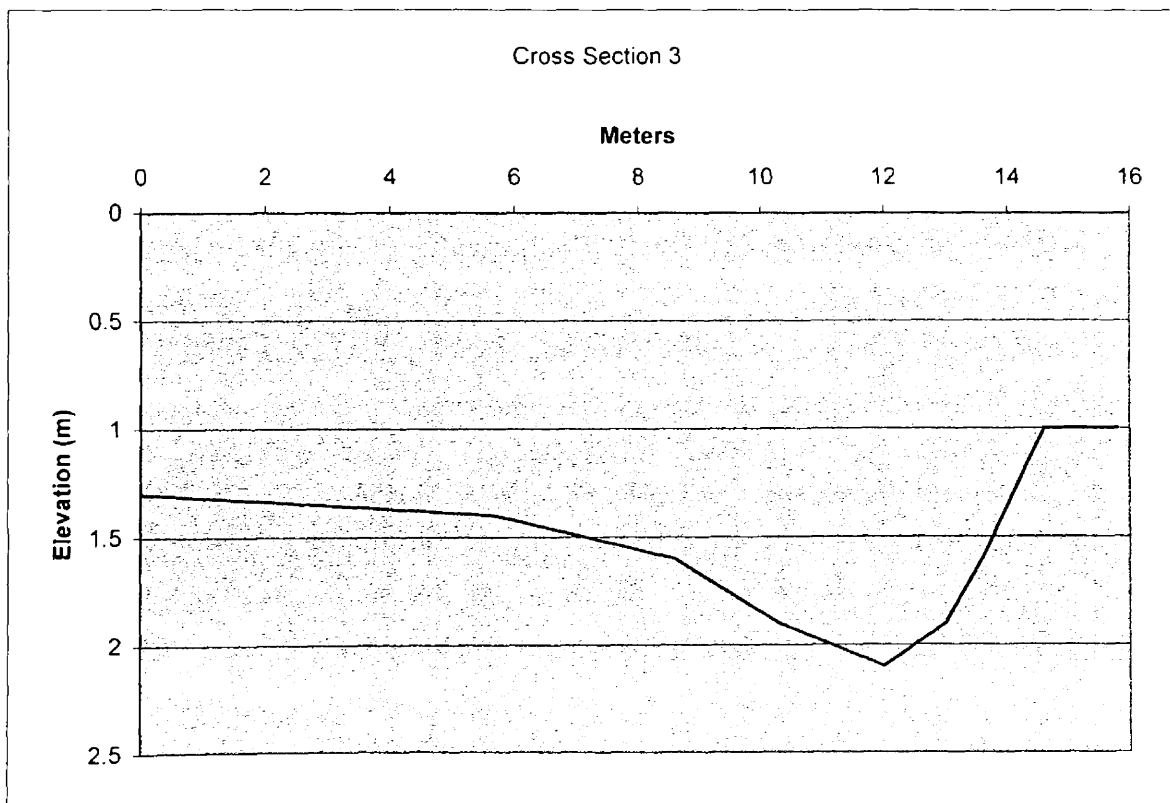


Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	down-fan reach of 6th DBF
Downstream distance	1700m
Cross Section Number	3
Notes	surveyed with hand level

X (m)	Y (m)	
0	1.3	REW
5.7	1.4	
8.6	1.6	
10.3	1.9	
12	2.1	thalweg
13	1.9	LEW
13.6	1.6	
14.6	1	
15.8	1	

REW = right edge water

LEW = left edge water

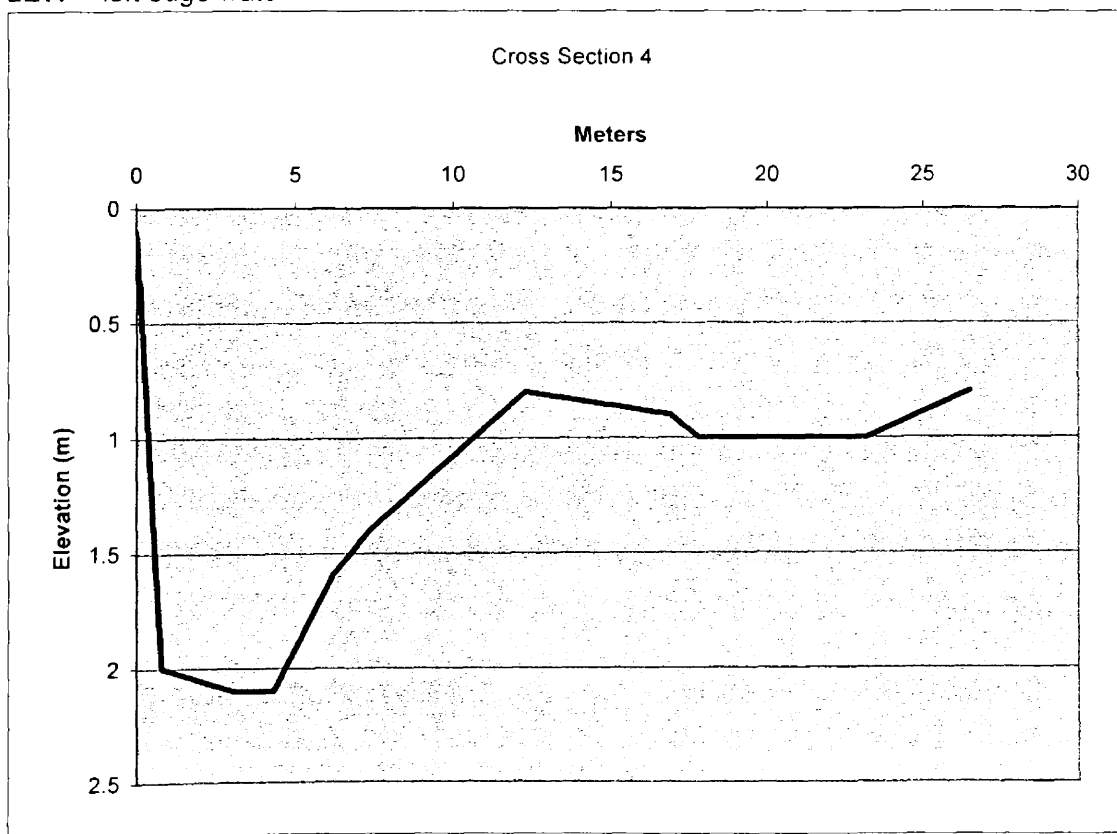


Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	up-fan reach of 5th DBF
Downstream distance	3500m
Cross Section Number	4
Notes	surveyed with hand level

X (m)	Y (m)	
0	0.1	
0.8	2	REW
3	2.1	
4.3	2.1	thalweg
6.2	1.6	
7.4	1.4	LEW
12.3	0.8	
16.9	0.9	
17.8	1	
23.2	1	
26.5	0.8	

REW = right edge water

LEW = left edge water

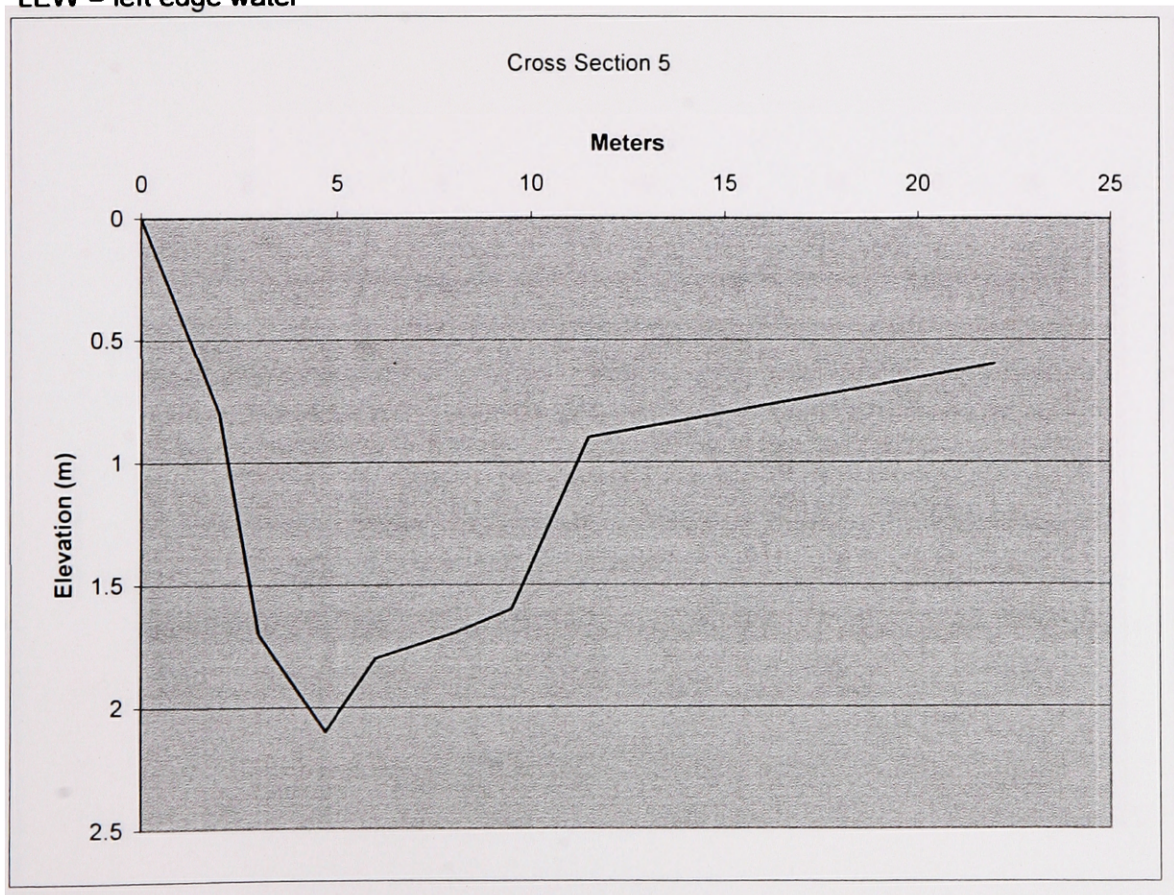


Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	Fan reach of 5th DBF
Downstream distance	3540m
Cross Section Number	5
Notes	surveyed with hand level

X (m)	Y (m)	
0	0	LEW thalweg
2	0.8	
3	1.7	
4.7	2.1	
6	1.8	
8	1.7	REW
9.5	1.6	
11.5	0.9	
22	0.6	

REW = right edge water

LEW = left edge water

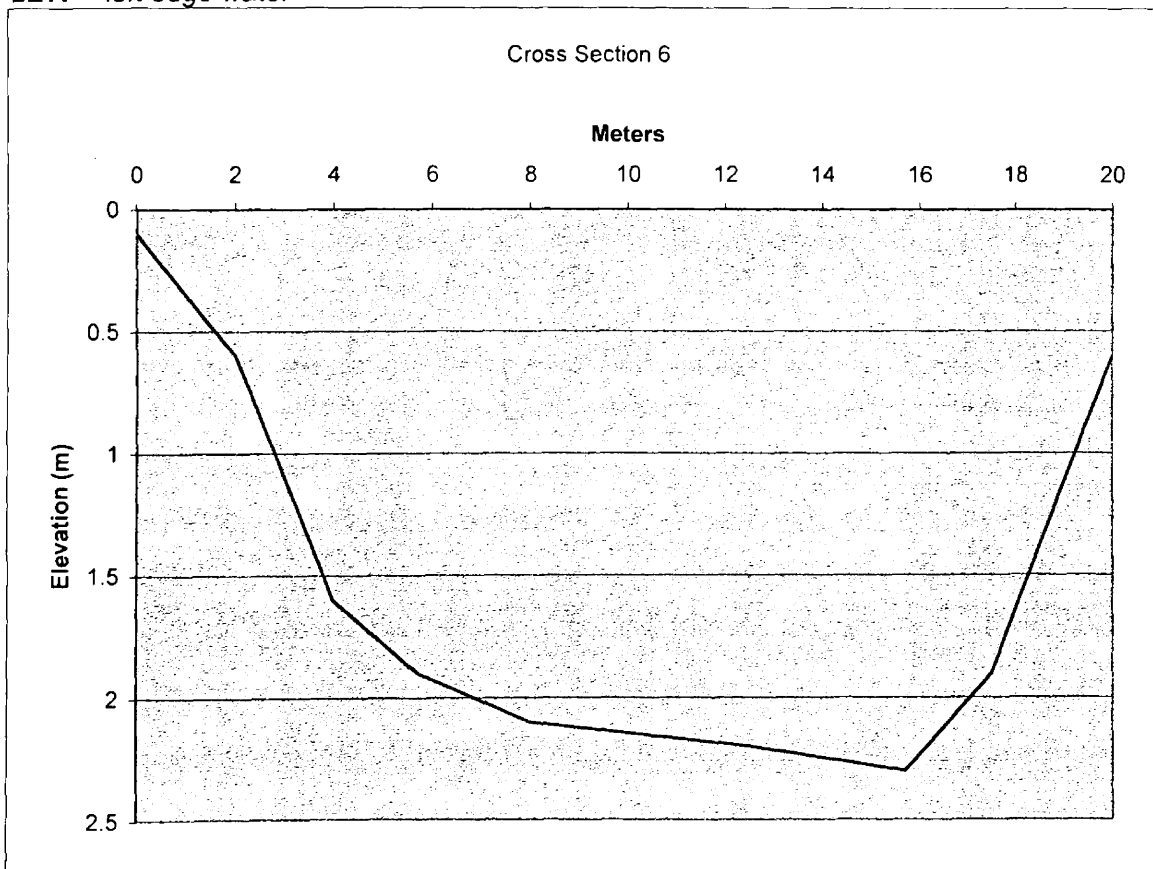


Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	down-fan reach of 5th DBF
Downstream distance	3580m
Cross Section Number	6
Notes	surveyed with hand level

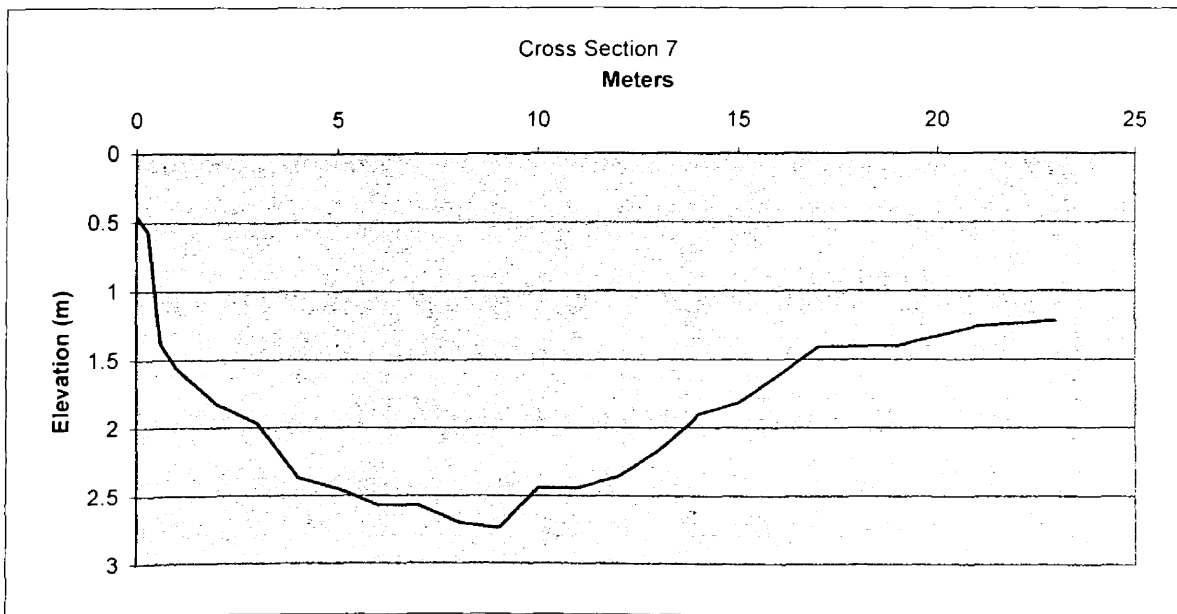
X (m)	Y (m)	
0	0.1	LEW
2	0.6	
4	1.6	
5.7	1.9	
8	2.1	
12.5	2.2	thalweg REW
15.7	2.3	
17.5	1.9	
20	0.6	

REW = right edge water

LEW = left edge water



Stream		Sleeping Child Creek
Date		4/16/2005
Observers		Hoffman
Location		up-fan reach of 4th DBF
Downstream distance		5360m
Cross Section Number		7
Notes		surveyed with transit
X (m)	Y(m)	
0	0.45	
0.3	0.57	
0.6	1.38	
1	1.56	
2	1.83	
3	1.97	
4	2.37	
5	2.45	
6	2.57	
7	2.57	
8	2.7	
9	2.74	
10	2.44	
11	2.44	
12	2.36	
13	2.17	
13.85	1.96	
14	1.9	
15	1.82	
16	1.62	
17	1.41	
19	1.4	
21	1.26	
23	1.22	



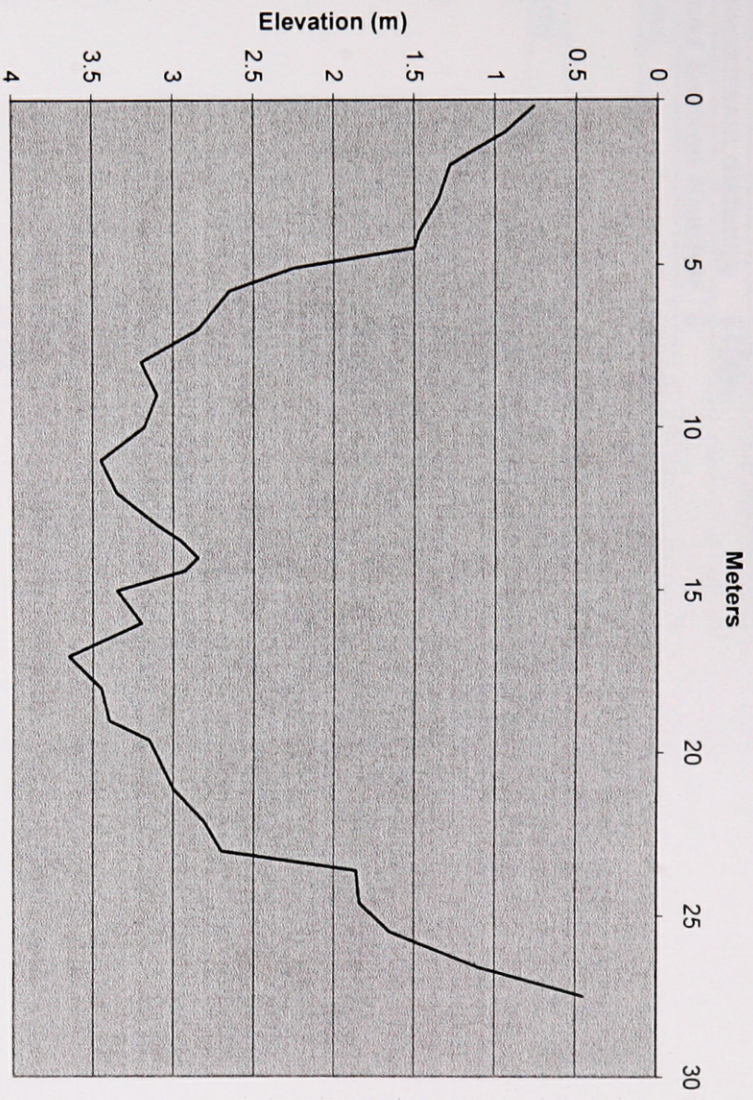
Stream	Sleeping Child Creek
Date	4/16/2005
Observers	Hoffman
Location	Fan reach of 4th DBF
Downstream distance	5380m
Cross Section Number	8
Notes	surveyed with transit

X (m)	Y (m)	
0.2	0.76	
1	0.94	
1.6	1.15	
2	1.28	
3	1.35	
4	1.47	
4.5	1.5	
5.1	2.25	
5.8	2.65	REW
7	2.85	
8	3.2	
9	3.1	
10	3.18	
11	3.45	
12	3.35	
13	3.1	
13.5	2.95	
14	2.85	
14.4	2.93	
15	3.35	
16	3.2	
17	3.65	thalweg
18	3.45	
19	3.4	
19.6	3.15	LEW
21.1	3	
22.1	2.81	
23	2.7	
23.6	1.86	
24.6	1.84	
25.5	1.65	
26.6	1.1	
27.5	0.45	

REW = right edge water

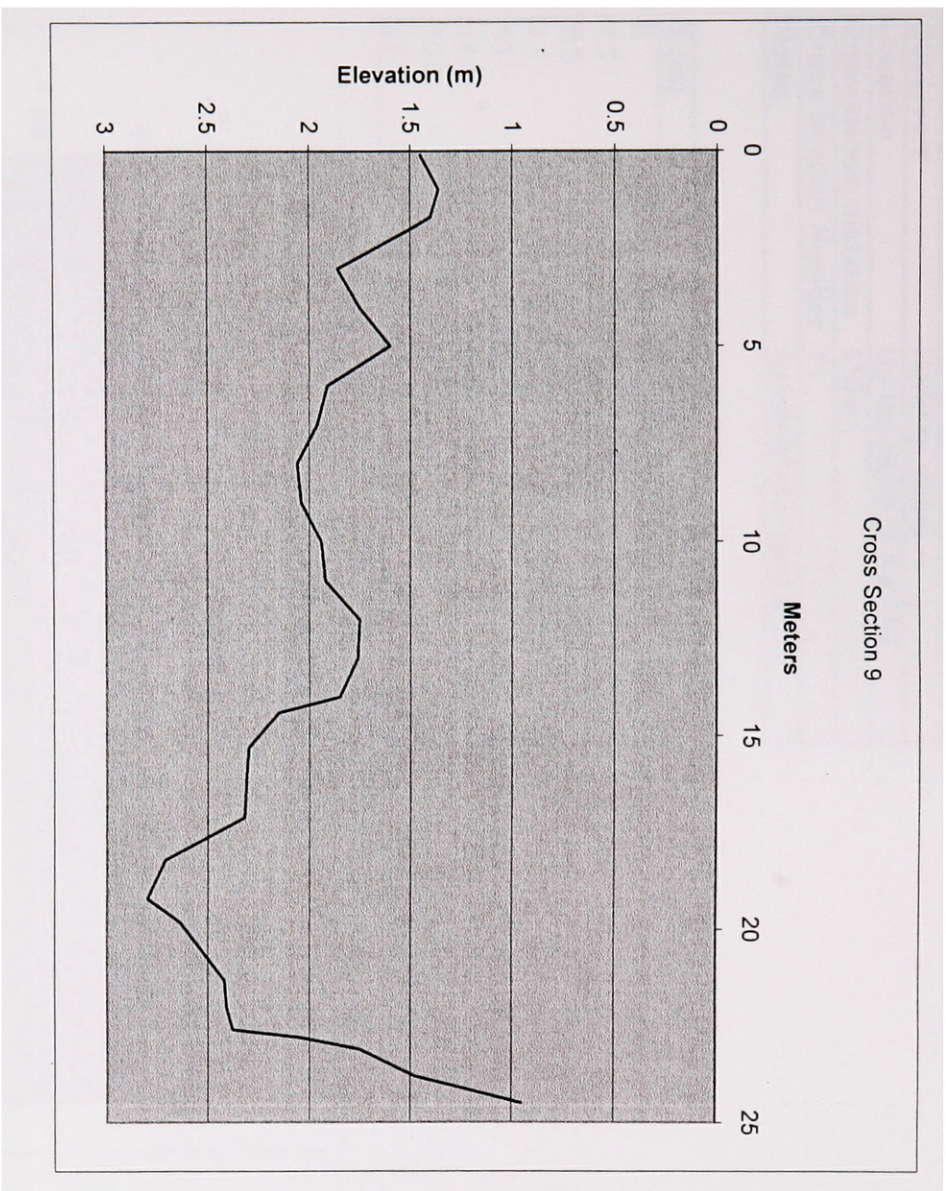
LEW = left edge water

Cross Section 8



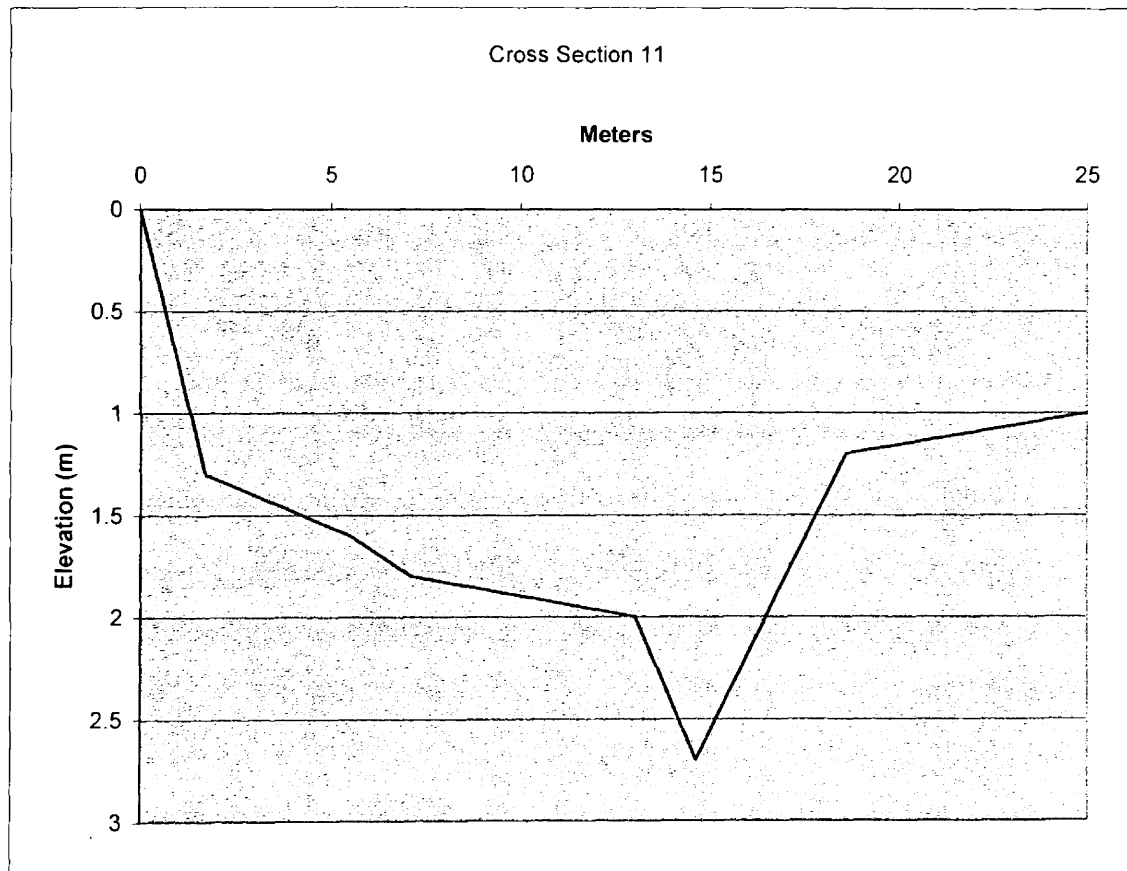
Stream	Sleeping Child Creek
Date	4/16/2005
Observers	Hoffman
Location	down-fan reach of 4th DBF
Downstream distance	5400m
Cross Section Number	9
Notes	surveyed with transit

X (m)	Y (m)
0.1	1.45
1	1.36
1.7	1.4
2	1.5
3	1.86
4	1.75
5	1.6
6	1.91
7	1.96
8	2.06
9	2.04
10	1.94
11	1.92
12	1.75
13	1.76
14	1.85
14.4	2.15
15.3	2.3
16	2.31
17.1	2.32
18.2	2.71
19.2	2.8
19.8	2.64
20.4	2.55
21.3	2.42
22	2.41
22.6	2.38
22.8	2.05
23.1	1.75
23.8	1.48
24.5	0.95



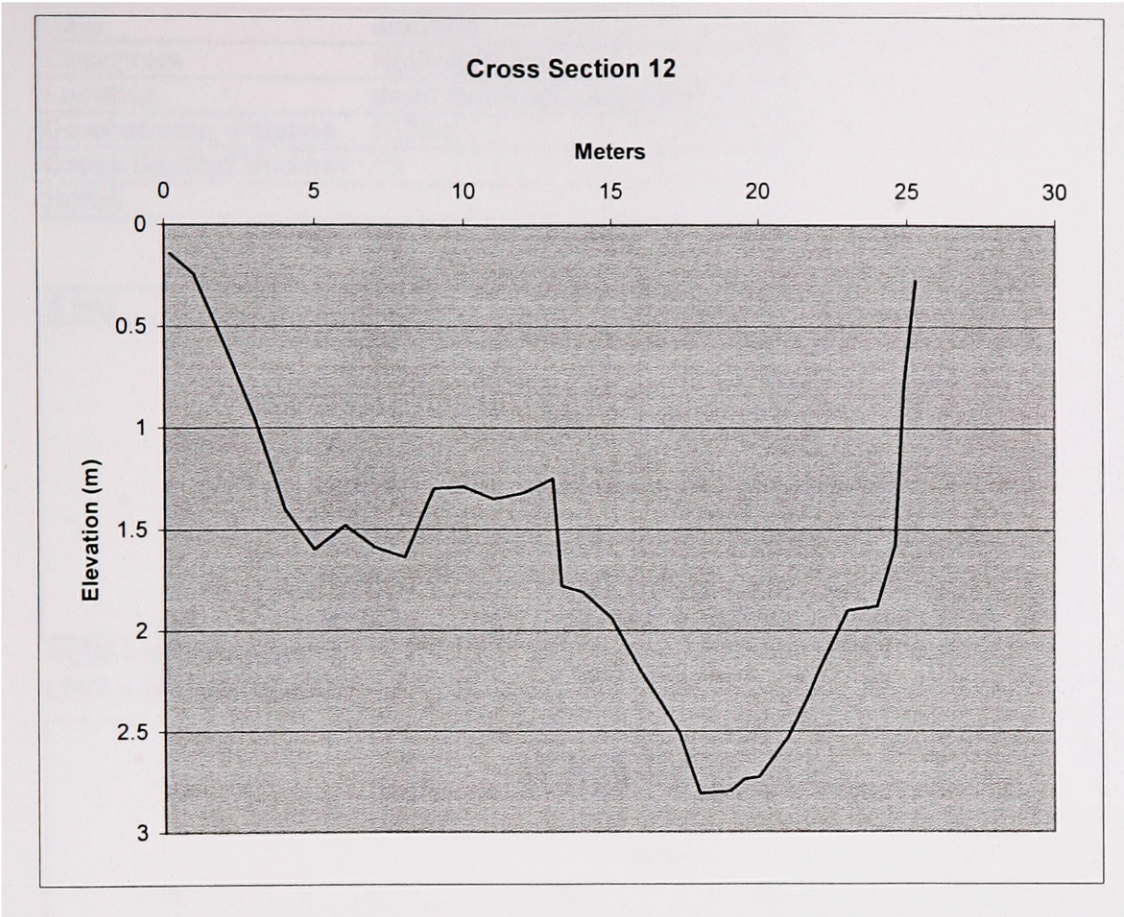
Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	Up-fan reach of 3rd DBF
Downstream distance	5504m
Cross Section Number	11
Notes	surveyed with hand level

X (m)	Y (m)
0	0
1.7	1.3
5.5	1.6
7.1	1.8
13	2
14.6	2.7
18.6	1.2
25	1



Stream	Sleeping Child Creek
Date	4/16/2005
Observers	Hoffman
Location	Fan reach of 3rd DBF
Downstream distance	5616m
Cross Section Number	12
Notes	surveyed with transit

X (m)	Y (m)
0.2	0.14
1	0.24
2	0.59
3	0.95
4	1.4
5	1.6
6	1.48
7	1.59
8	1.64
9	1.3
10	1.29
11	1.35
12	1.32
13	1.25
13.3	1.78
14	1.81
15	1.94
16	2.2
16.6	2.34
17.3	2.51
18	2.81
19	2.8
19.5	2.74
20	2.73
21	2.53
21.7	2.32
22	2.21
23	1.9
24	1.88
24.6	1.58
24.9	0.8
25.3	0.27

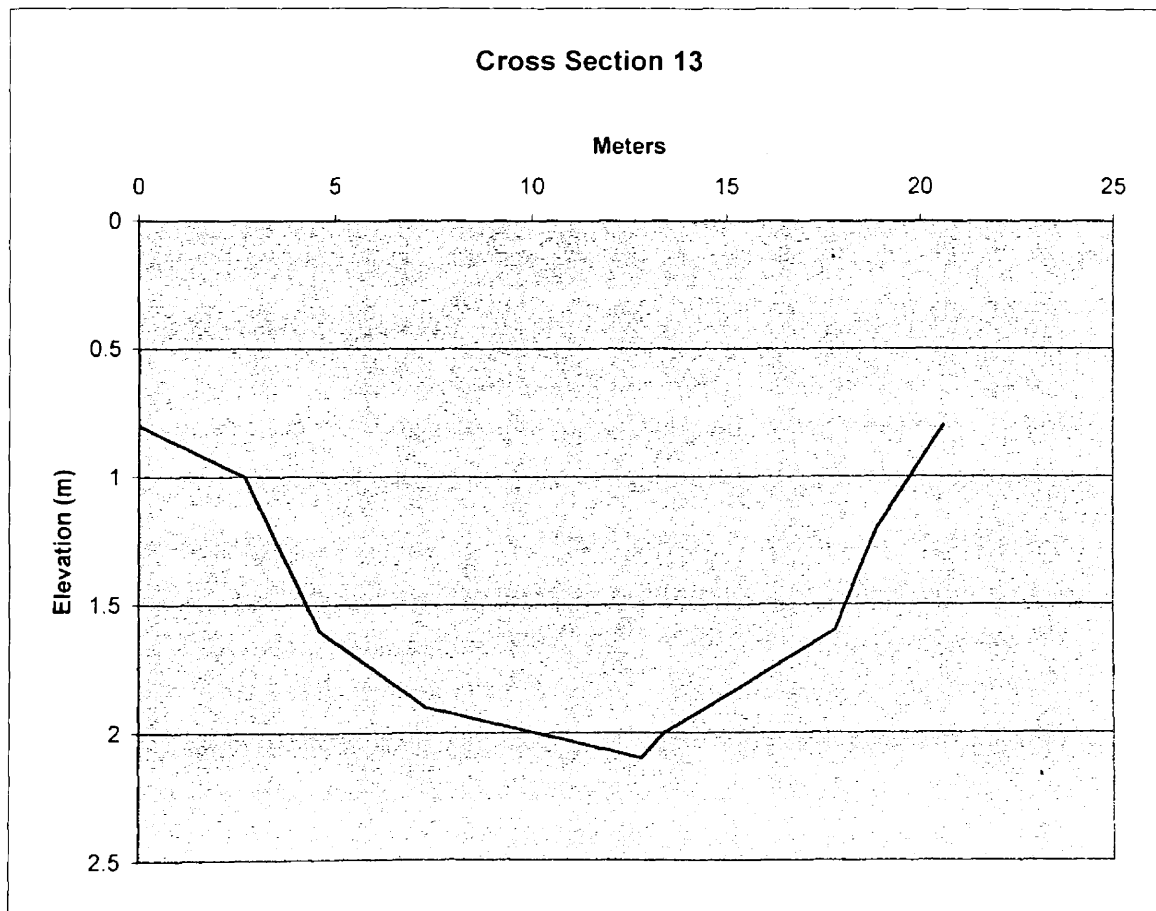


Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	down-fan reach of 3rd DBF
Downstream distance	5636m
Cross Section Number	13
Notes	

X (m)	Y (m)	
0	0.8	
2.7	1	
4.6	1.6	REW
7.3	1.9	
12.8	2.1	thalweg
13.4	2	
17.8	1.6	LEW
18.9	1.2	
20.6	0.8	

REW = right edge water

LEW = left edge water

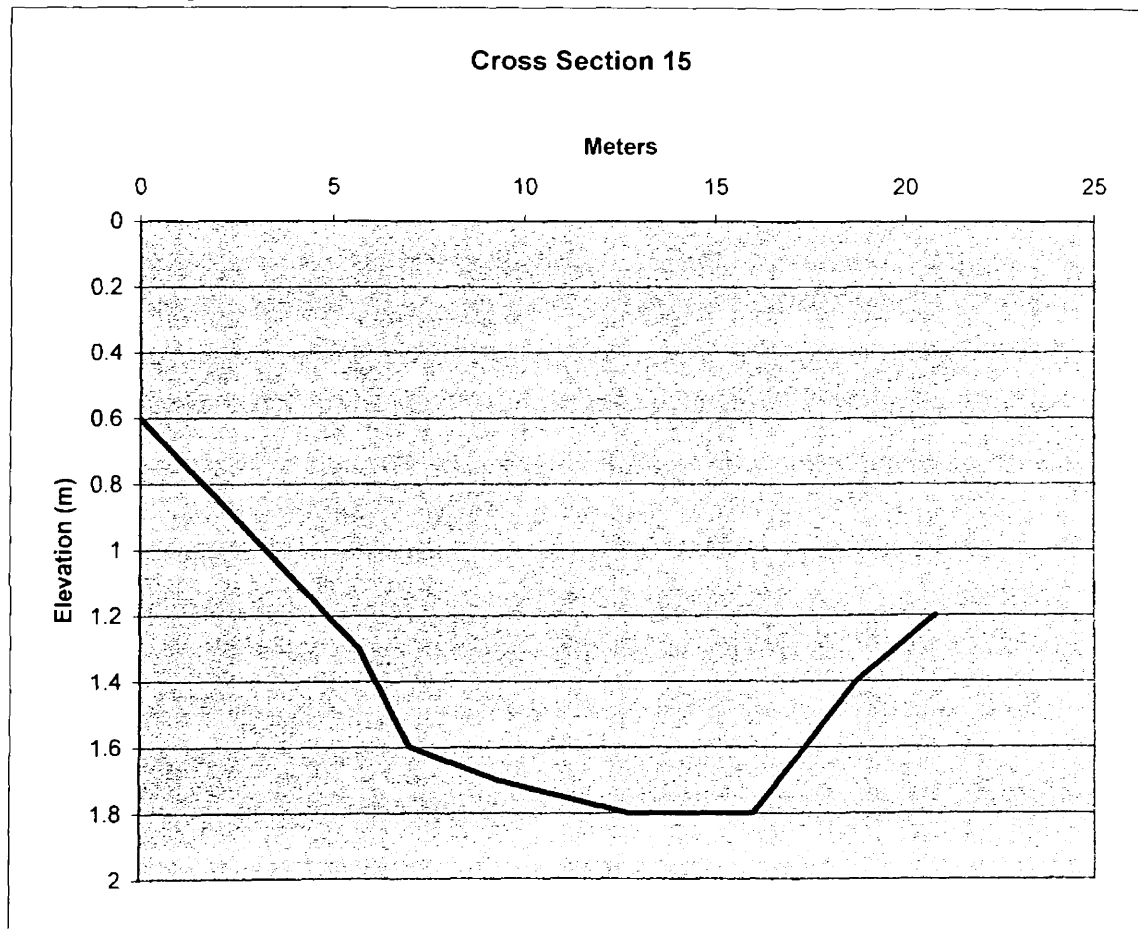


Stream	Sleeping Child Creek
Date	8/10/2005
Observers	Hoffman, Burns
Location	up-fan reach of 2nd DBF
Downstream distance	5892m
Cross Section Number	15
Notes	surveyed with hand level

X (m)	Y (m)
0	0.6
5.7	1.3
7	1.6
9.3	1.7
12.7	1.8
16	1.8
18.7	1.4
20.8	1.2

REW = right edge water

LEW = left edge water

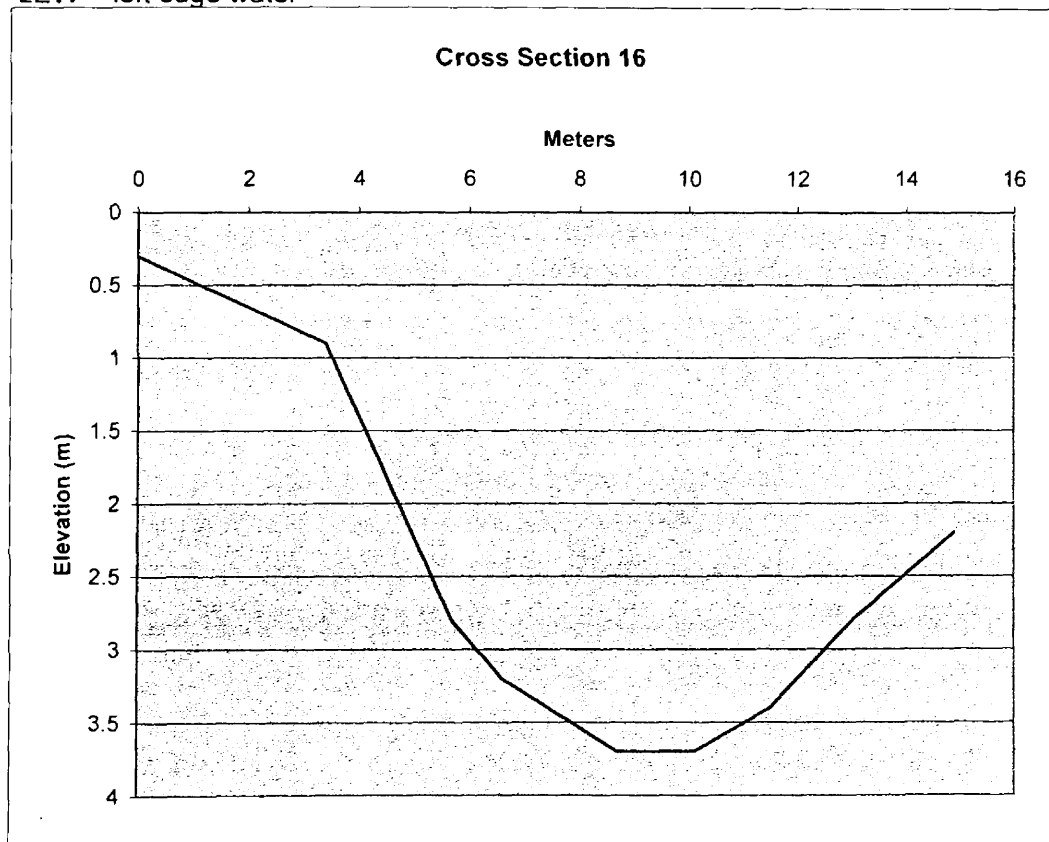


Stream	Sleeping Child Creek
Date	8/10/2005
Observers	Hoffman, Burns
Location	fan reach of 2nd DBF
Downstream distance	5902m
Cross Section Number	16
Notes	surveyed with hand level

X (m)	Y (m)	
0	0.3	
3.4	0.9	
5.7	2.8	
6.6	3.2	REW
8.7	3.7	
10.1	3.7	
11.5	3.4	LEW
13	2.8	
14.9	2.2	

REW = right edge water

LEW = left edge water

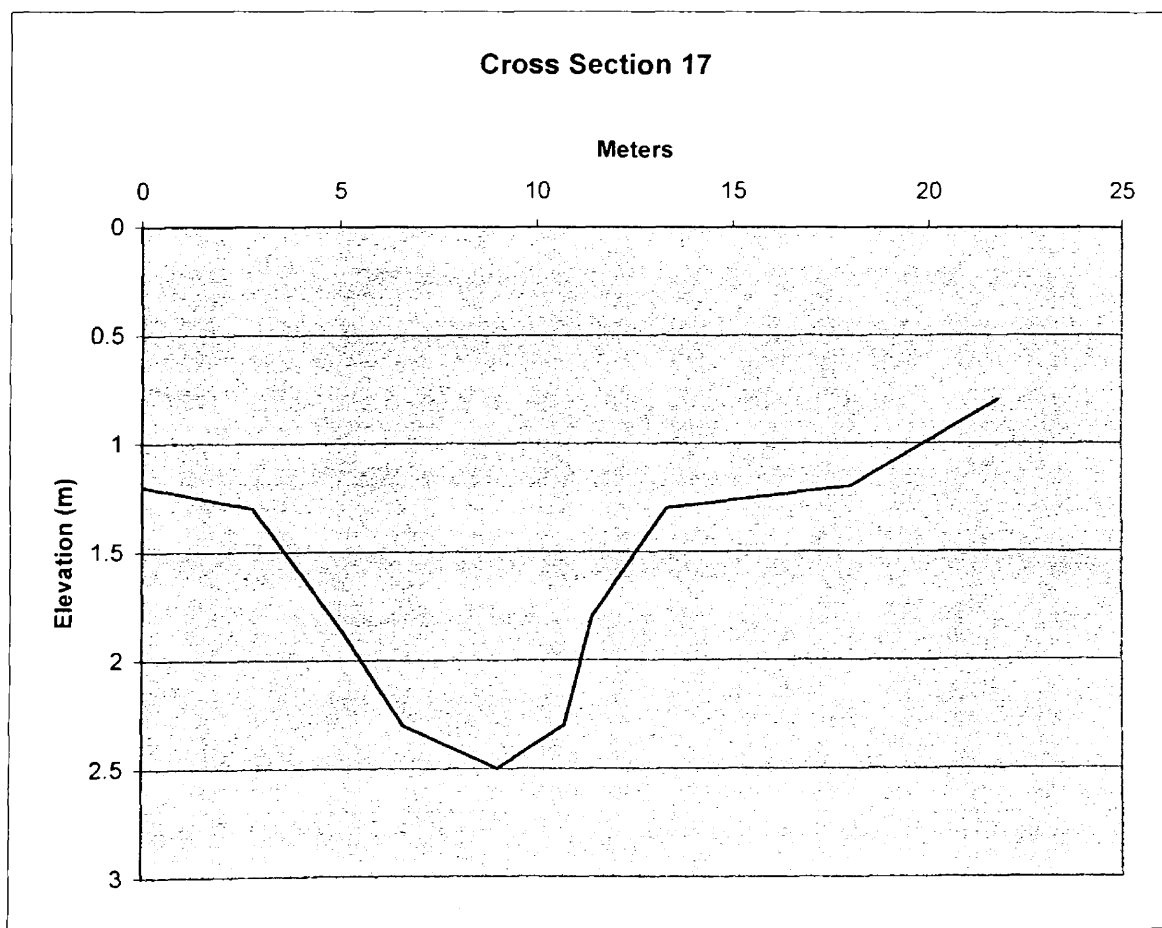


Stream	Sleeping Child Creek
Date	8/10/2005
Observers	Hoffman, Burns
Location	down-fan reach of 2nd DBF
Downstream distance	5912m
Cross Section Number	17
Notes	surveyed with hand level

X (m)	Y (m)	
0	1.2	
2.8	1.3	
5.2	1.9	REW
6.6	2.3	
9	2.5	thalweg
10.7	2.3	
11.4	1.8	LEW
13.3	1.3	
18	1.2	
21.8	0.8	

REW = right edge water

LEW = left edge water



Stream	Sleeping Child Creek
Date	8/10/2005
Observers	Hoffman, Burns
Location	up-fan reach of 1st DBF
Downstream distance	6310m
Cross Section Number	19
Notes	surveyed with hand level

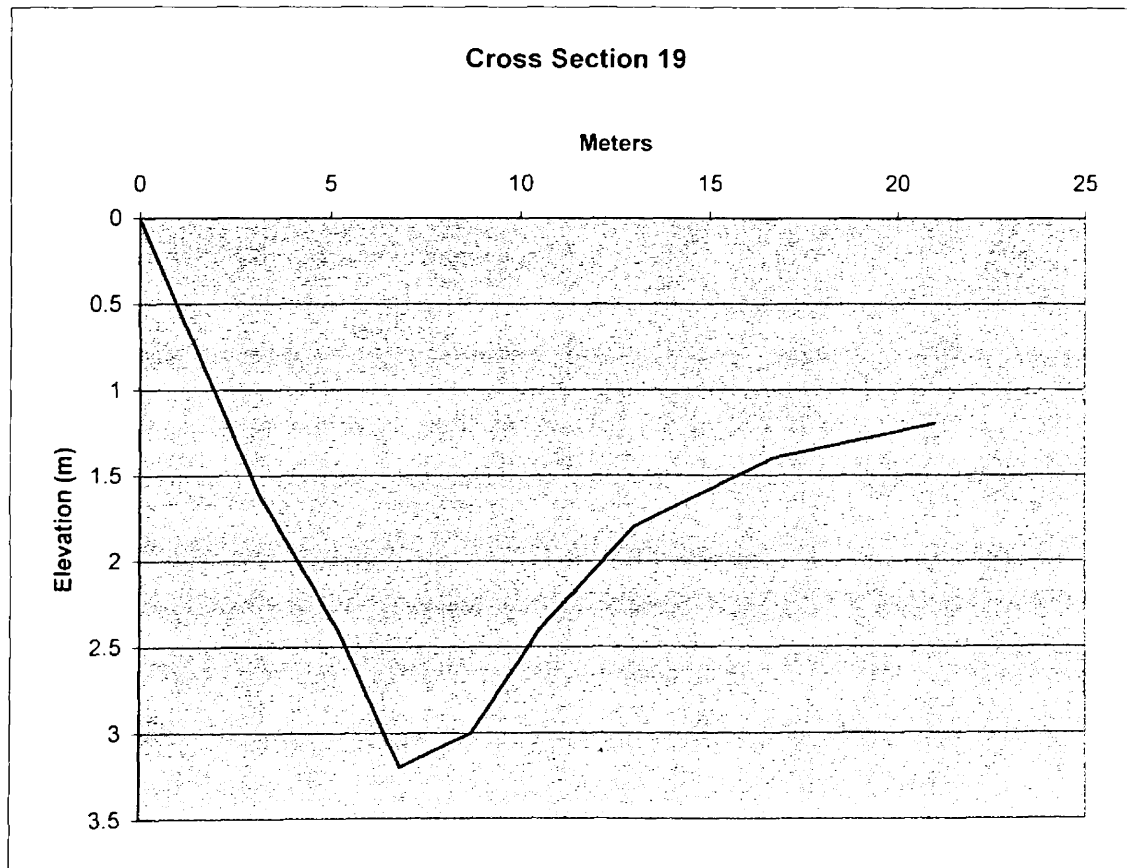
X (m)	Y (m)	
0	0	
3.1	1.6	
5.2	2.4	
6.8	3.2	
8.7	3	
10.5	2.4	
13	1.8	
16.7	1.4	
21	1.2	

REW
thalweg

LEW

REW = right edge water

LEW = left edge water

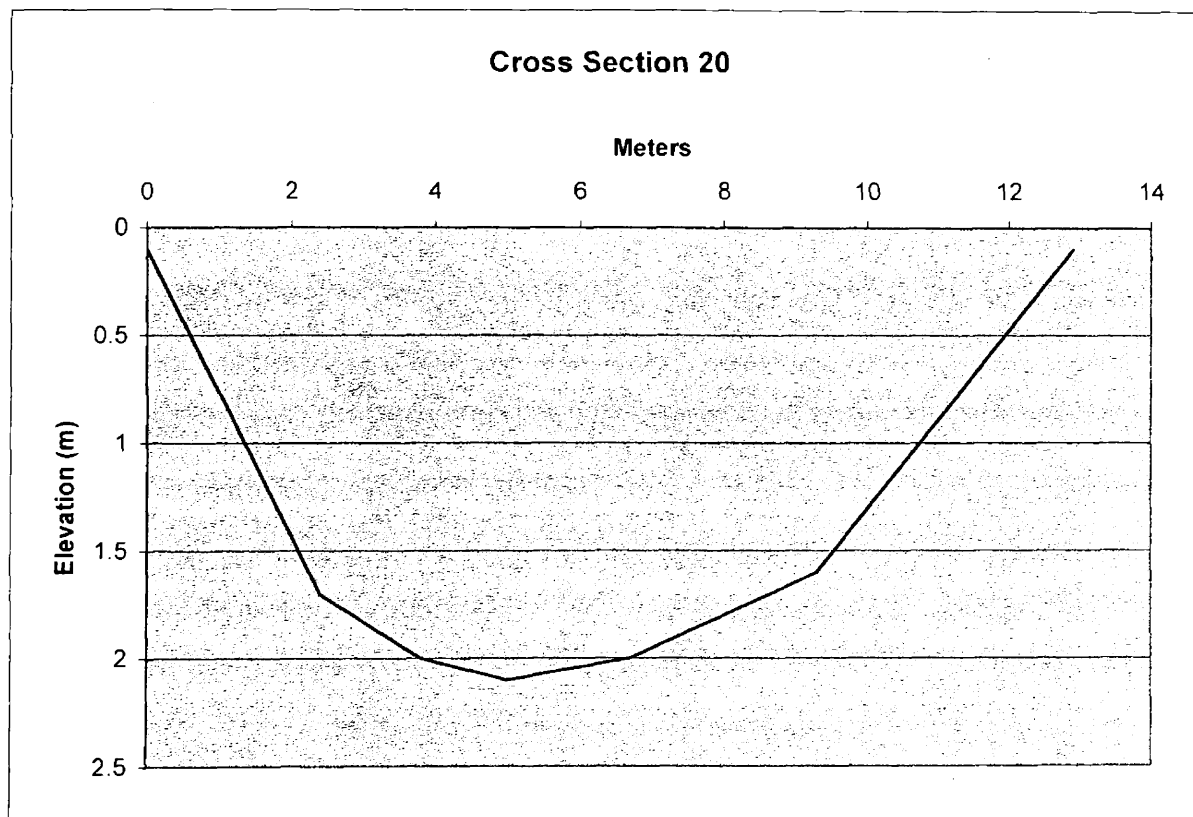


Stream	Sleeping Child Creek
Date	8/10/2005
Observers	Hoffman, Burns
Location	fan reach of 1st DBF
Downstream distance	6330m
Cross Section Number	20
Notes	surveyed with hand level

X (m)	Y (m)	
0	0.1	REW
2.4	1.7	
3.8	2	
5	2.1	
6.7	2	LEW
9.3	1.6	
12.9	0.1	

REW = right edge water

LEW = left edge water

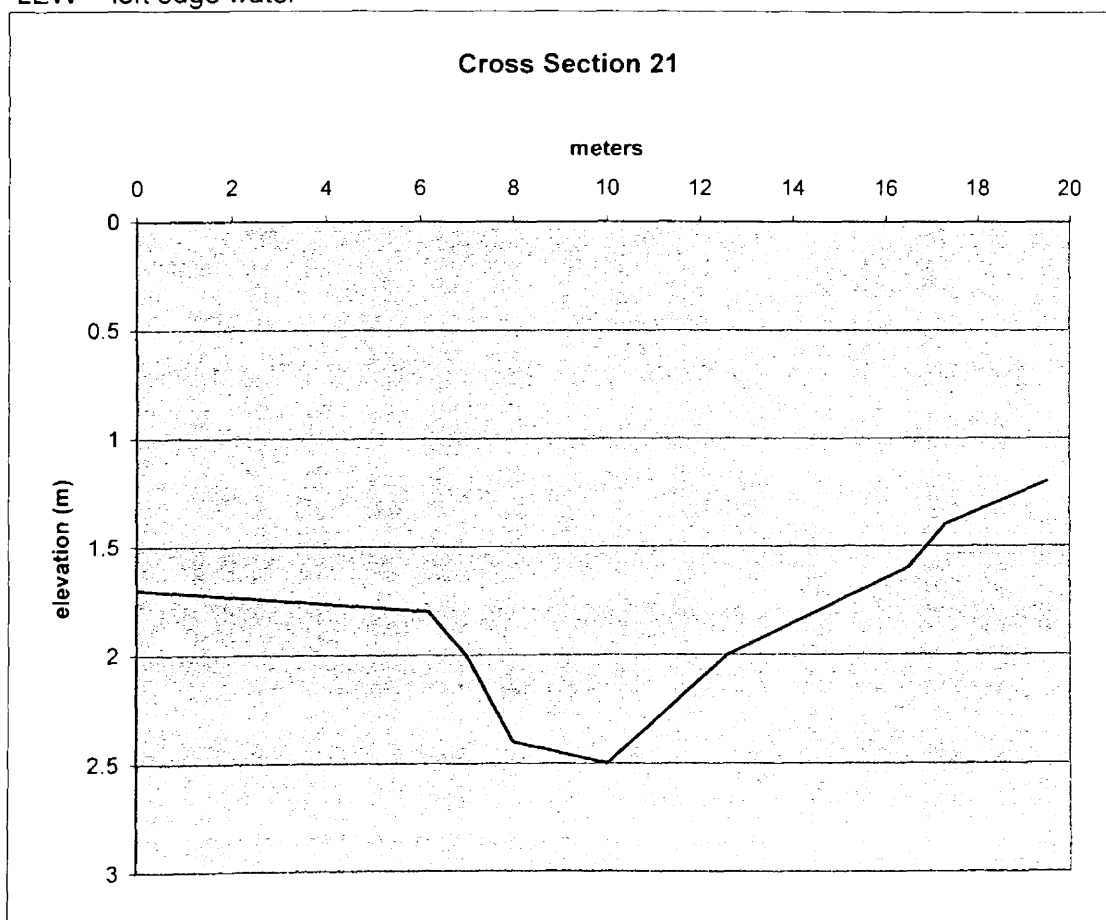


Stream	Sleeping Child Creek
Date	8/10/2005
Observers	Hoffman, Burns
Location	down-fan reach of 1st DBF
Downstream distance	6350m
Cross Section Number	21
Notes	surveyed with hand level

X (m)	Y (m)	
0	1.7	REW
6.2	1.8	
7	2	
8	2.4	
10	2.5	thalweg LEW
12.6	2	
16.5	1.6	
17.3	1.4	
19.5	1.2	

REW = right edge water

LEW = left edge water



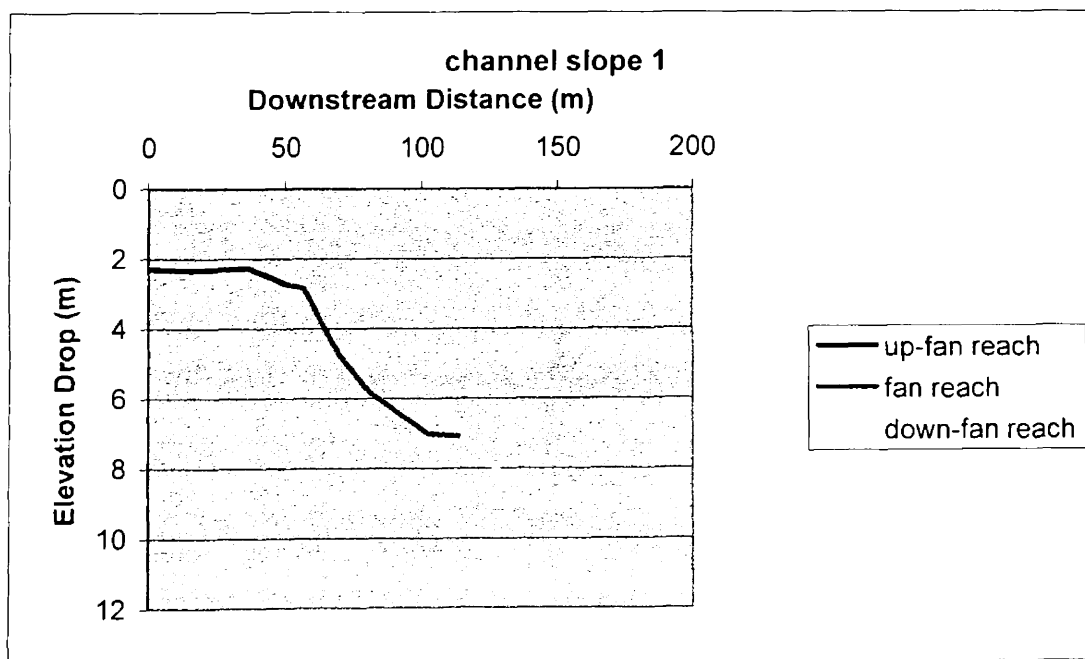
APPENDIX B

CHANNEL SLOPE SURVEYS

Stream	Sleeping Child Creek
Date	7/19/2005
Observers	Hoffman, Burns
Location	6th DBF
Downstream distance	1630m
Channel slope number	1
Instrument height:	1.38m
Notes	

Channel slope:	
up-fan reach:	0.008549
fan reach:	0.067438
down-fan reach:	0.037178

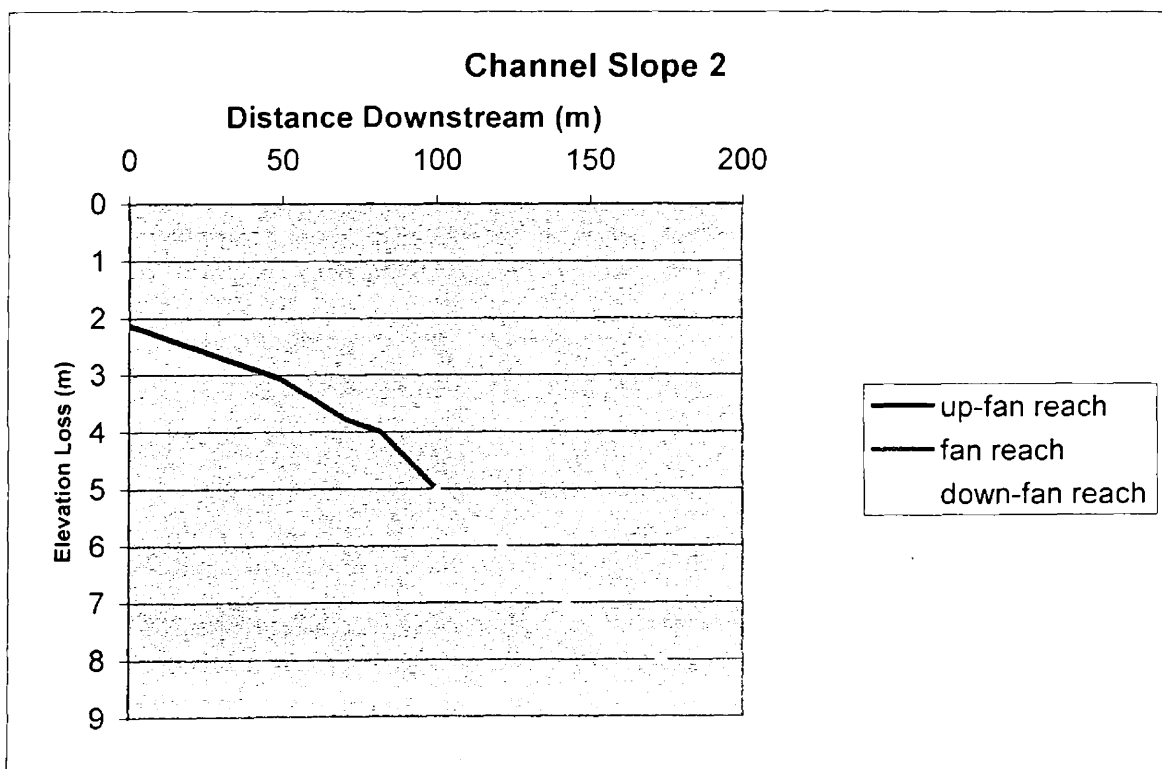
X(m)	Y(m)	comments
0	2.3	border of up-fan reach and fan reach
16.4	2.34	
36.5	2.27	
50.3	2.73	
57	2.85	
70	4.77	border of fan reach and down-fan reach
81	5.83	
102.2	7.01	
115.1	7.1	
132.5	8.38	
151.1	8.38	
181	9.55	



Stream	Sleeping Child Creek
Date	7/19/2005
Observers	Hoffman, Burns
Location	5th DBF
Downstream distance	3500m
Channel slope number	2
Instrument height	1.32m
Notes	

Channel slope:	
up-fan reach:	0.019148
fan reach:	0.038067
down-fan reach:	0.0408

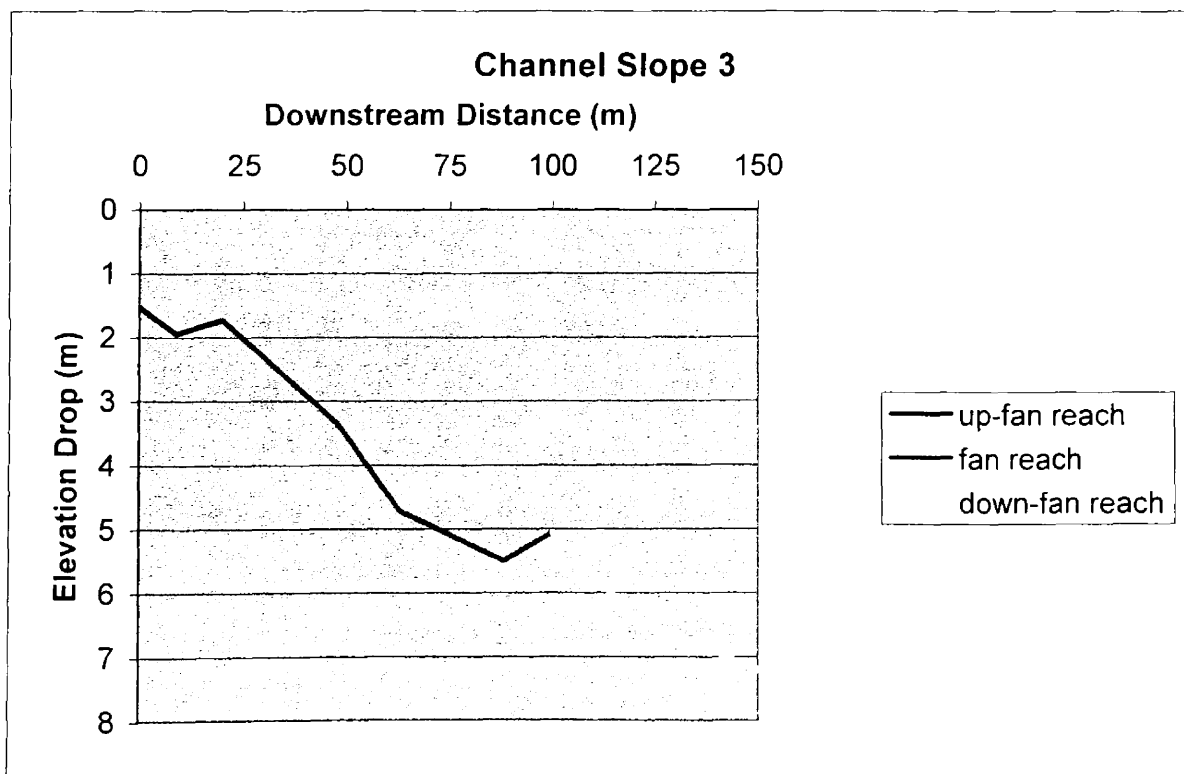
X(m)	Y(m)	comments
0	2.126	
49.3	3.07	border of up-fan reach and fan reach
71	3.79	
82	4	
100	5	border of fan reach and down-fan reach
119	5.89	
146	7.19	
175	8.06	



Stream Sleeping Child Creek
Date 7/19/2005
Observers Hoffman, Burns
Location 4th DBF
Downstream distance 5360m
Channel slope number 3
Instrument height 1.39m
Notes

Channel slope:	
up-fan reach	0.0105
fan reach	0.041625
down-fan reach	0.042801

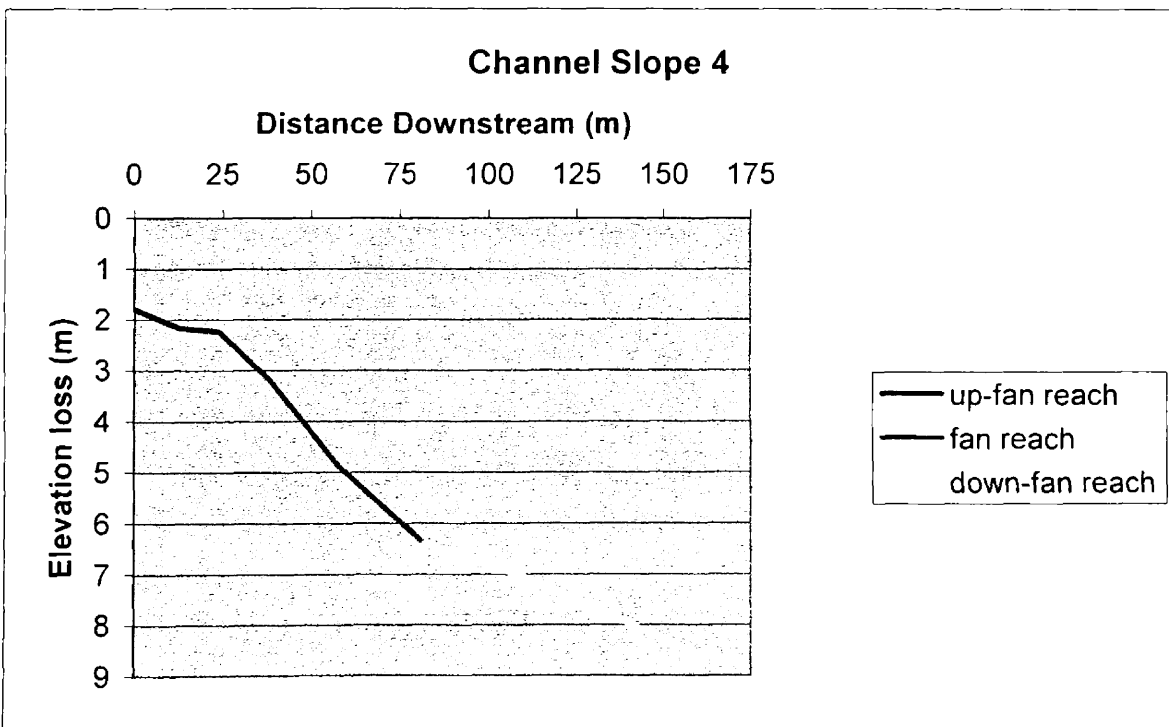
X(m)	Y(m)	comments
0	1.52	border of up-fan reach and fan reach
9	1.95	
20	1.73	
35	2.61	
48	3.36	
63	4.72	border of fan reach and down-fan reach
88	5.5	
100	5.06	
120.5	6.41	
150.7	7.23	



Stream Sleeping Child Creek
Date 7/20/2005
Observers Hoffman, Burns
Location 3rd DBF
Downstream distance 5616m
Channel slope number 4
Instrument height 1.58m
Notes

Channel slope:	
up-fan reach	0.01875
fan reach	0.071724
down-fan reach	0.028052

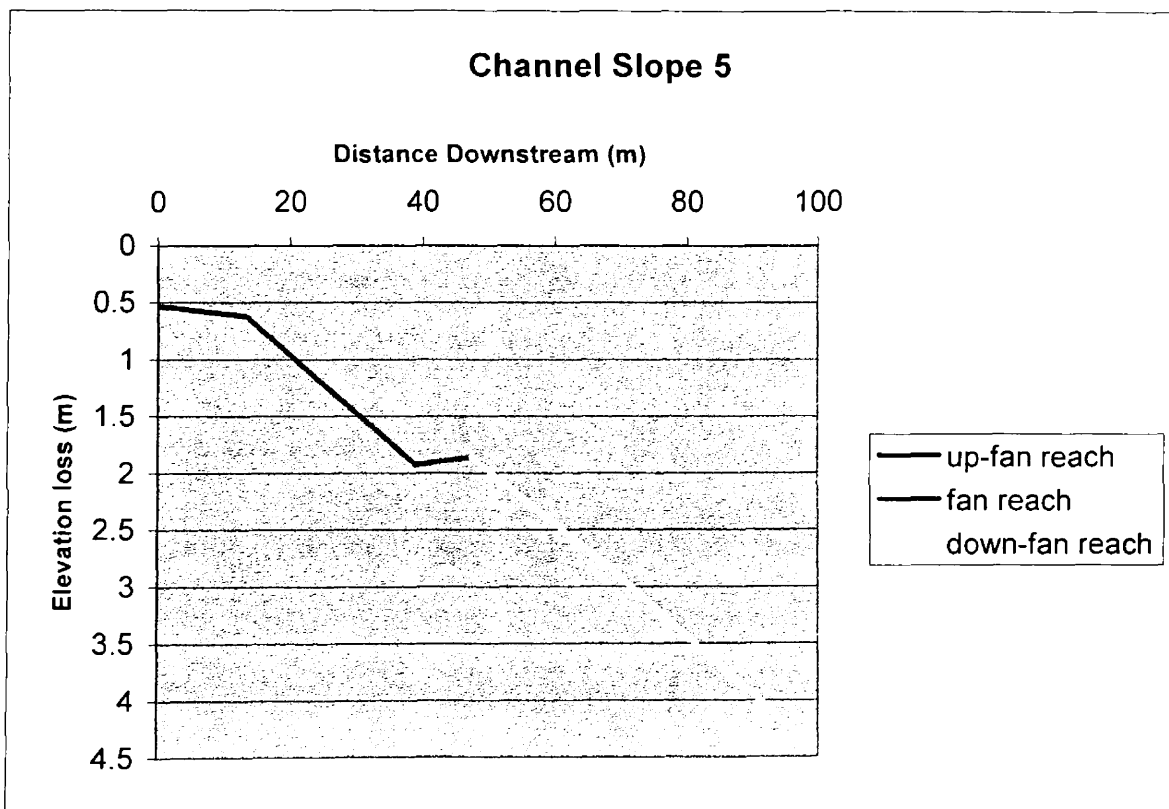
X(m)	Y(m)	comments
0	1.79	
13	2.17	
24	2.24	border of up-fan reach and fan reach
38	3.18	
58	4.89	
82	6.4	Border of fan reach and down-fan reach
111	7.08	
159	8.56	



Stream Sleeping Child Creek
Date 7/20/2005
Observers Hoffman, Burns
Location 2nd DBF
Downstream distance 5892m
Channel slope number 5
Instrument height 1.29m
Notes

Channel slope:	
up-fan reach	0.006818
fan reach	0.036152
down-fan reach	0.047112

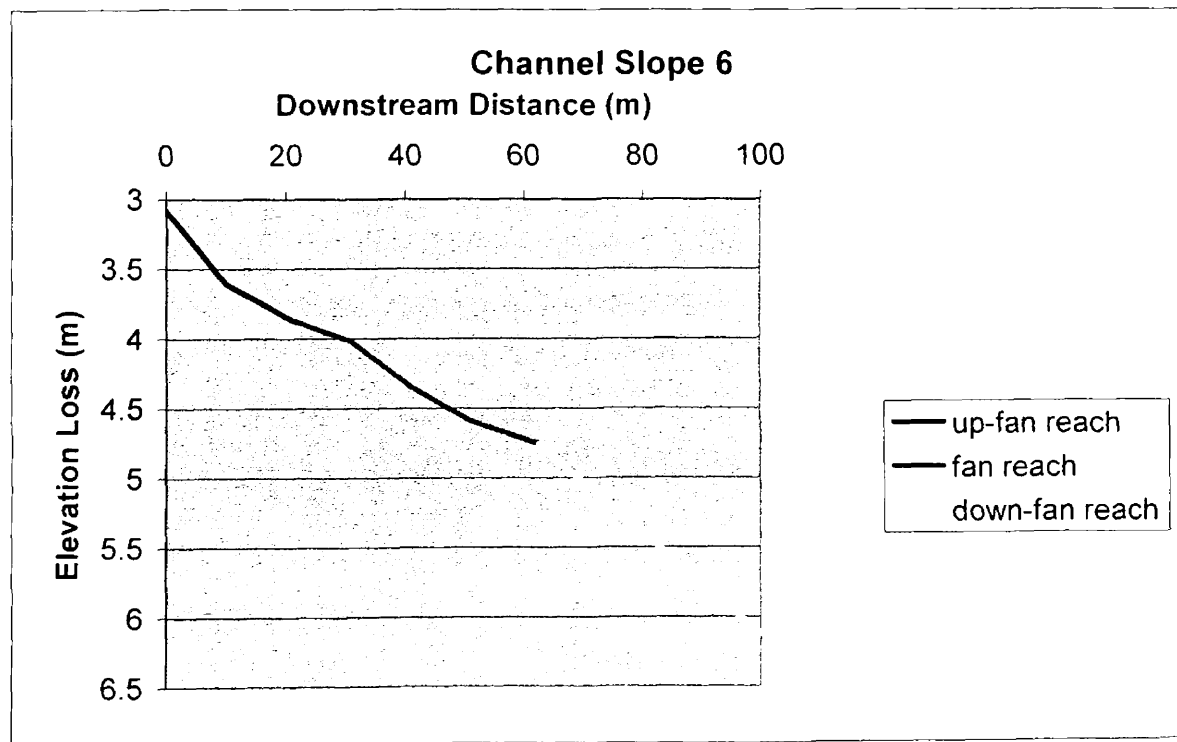
X(m)	Y(m)	comments
0	0.53	
13.2	0.62	border of up-fan reach and fan reach
39	1.93	
47.5	1.86	border of fan reach and down-fan reach
68	2.82	
96	4.25	



Stream	Sleeping Child Creek
Date	7/20/2005
Observers	Hoffman, Burns
Location	1st DBF
Downstream distance	6310m
Channel slope number	6
Instrument height	1.52m
Notes	

Channel slope	
up-fan reach	0.037619
fan reach	0.021394
down-fan reach	0.036631

X(m)	Y(m)	comments
0	3.08	
10	3.61	
21	3.87	border of up-fan reach and down-fan reach
31	4.02	
41.4	4.36	
51	4.59	
62.6	4.76	border of fan-reach and down-fan reach
100	6.13	



APPENDIX C

PEBBLE COUNTS

Stream	Sleeping Child Creek
Date	7/11/2004
Observers	Perez
Location	up-fan reach 6th DBF
Downstream Distance	1630m
Associated cross section	1
Notes	

grain size (mm)	percent finer than
2	79
2.8	79
4	79
5.6	92
8	96
11	100
16	100
22	100
32	100
45	100
64	100
90	100
128	100
180	100
256	100
360	100
512	100

Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	fan reach 6th DBF
Downstream Distance	1660
Associated cross section	2
Notes	

grain size (mm)	percent finer than
2	10
2.8	13
4	13
5.6	13
8	14
11	14
16	15
22	15
32	15
45	17
64	28
90	42
128	60
180	68
256	71
360	71
512	100

Stream	Sleeping Child Creek
Date	7/11/2004
Observers	Perez
Location	down-fan reach 6th DBF
Downstream Distance	1700
Associated cross section	3
Notes	

grain size (mm)	percent finer than
2	9
2.8	9
4	9
5.6	10
8	12
11	12
16	12
22	13
32	16
45	22
64	33
90	49
128	62
180	78
256	89
360	95
512	100

Stream	Sleeping Child Creek
Date	7/11/2004
Observers	Perez
Location	up-fan reach 5th DBF
Downstream Distance	3500
Associated cross section	4
Notes	

grain size (mm)	percent finer than
2	27
2.8	27
4	28
5.6	32
8	36
11	50
16	65
22	83
32	91
45	96
64	97
90	98
128	98
180	99
256	100
360	100
512	100

Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	fan reach 5th DBF
Downstream Distance	3540m
Associated cross section	5
Notes	

grain size (mm)	percent finer than
2	0
2.8	0
4	1
5.6	1
8	1
11	1
16	3
22	3
32	3
45	5
64	6
90	19
128	37
180	47
256	63
360	75
512	80

Stream	Sleeping Child Creek
Date	7/11/2004
Observers	Perez
Location	down-fan reach 5th DBF
Downstream Distance	3580m
Associated cross section	6
Notes	

grain size (mm)	percent finer than
2	6
2.8	6
4	6
5.6	6
8	6
11	6
16	6
22	7
32	7
45	8
64	12
90	16
128	22
180	37
256	59
360	72
512	77

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	up-fan channel 4th DBF
Downstream Distance	5360m
Associated cross section	7
Notes	

grain size (mm)	percent finer than
2	22
2.8	22
4	22
5.6	23
8	23
11	23
16	27
22	31
32	36
45	45
64	60
90	70
128	79
180	93
256	97
360	100
512	100

Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	fan reach 4th DBF
Downstream Distance	5380
Associated cross section	8
Notes	

grain size (mm)	percent finer than
2	7
2.8	7
4	7
5.6	8
8	8
11	8
16	8
22	9
32	10
45	14
64	20
90	27
128	41
180	56
256	71
360	80
512	80

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	down-fan reach 4th DBF
Downstream Distance	5400m
Associated cross section	9
Notes	

grain size (mm)	percent finer than
2	7
2.8	7
4	7
5.6	7
8	7
11	7
16	8
22	9
32	9
45	14
64	16
90	22
128	40
180	54
256	69
360	76
512	79

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	up-fan reach 3rd DBF
Downstream Distance	5616m
Associated cross section	11
Notes	

grain size (mm)	percent finer than
2	4
2.8	4
4	4
5.6	4
8	5
11	5
16	5
22	7
32	10
45	14
64	25
90	42
128	65
180	82
256	91
360	97
512	97

Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	fan reach 3rd DBF
Downstream Distance	5626m
Associated cross section	12
Notes	

grain size (mm)	percent finer than
2	9
2.8	9
4	9
5.6	10
8	10
11	10
16	12
22	14
32	17
45	21
64	26
90	39
128	52
180	58
256	69
360	77
512	78

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	down-fan reach 3rd DBF
Downstream Distance	5636m
Associated cross section	13
Notes	

grain size (mm)	percent finer than
2	3
2.8	3
4	3
5.6	3
8	3
11	4
16	4
22	4
32	6
45	7
64	15
90	29
128	40
180	59
256	70
360	76
512	79

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	up-fan reach 2nd DBF
Downstream Distance	5892m
Associated cross section	15
Notes	

grain size (mm)	percent finer than
2	13
2.8	13
4	14
5.6	15
8	15
11	16
16	16
22	16
32	17
45	22
64	30
90	41
128	63
180	83
256	96
360	100
512	100

Stream	Sleeping Child Creek
Date	8/9/2005
Observers	Hoffman, Burns
Location	fan reach 2nd DBF
Downstream Distance	5902m
Associated cross section	16
Notes	

grain size (mm)	percent finer than
2	7
2.8	7
4	7
5.6	7
8	7
11	7
16	7
22	7
32	12
45	24
64	28
90	39
128	64
180	76
256	81
360	85
512	86

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	down-fan reach 2nd DBF
Downstream Distance	5912m
Associated cross section	17
Notes	

grain size (mm)	percent finer than
2	8
2.8	8
4	8
5.6	8
8	8
11	8
16	8
22	8
32	9
45	12
64	15
90	22
128	33
180	44
256	69
360	80
512	84

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	up-fan reach 1st DBF
Downstream Distance	6310m
Associated cross section	19
Notes	

grain size (mm)	percent finer than
2	18
2.8	18
4	18
5.6	20
8	20
11	20
16	20
22	21
32	22
45	28
64	45
90	62
128	77
180	85
256	86
360	90
512	91

Stream	Sleeping Child Creek
Date	8/10/2005
Observers	Hoffman, Burns
Location	fan reach 1st DBF
Downstream Distance	6330m
Associated cross section	20
Notes	

grain size (mm)	percent finer than
2	6
2.8	6
4	6
5.6	6
8	6
11	6
16	6
22	9
32	10
45	10
64	21
90	29
128	44
180	58
256	70
360	76
512	80

Stream	Sleeping Child Creek
Date	7/10/2004
Observers	Perez
Location	down-fan reach 1st DBF
Downstream Distance	6350
Associated cross section	21
Notes	

grain size (mm)	percent finer than
2	11
2.8	11
4	11
5.6	11
8	11
11	14
16	16
22	17
32	21
45	26
64	33
90	38
128	52
180	62
256	81
360	92
512	95

APPENDIX D

POOL SURVEY

Stream	Sleeping Child Creek
Observers	Hoffman

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
0	p	1		0.7		Confluence of Divide Creek and Sleeping Child Creek
16	r		0.3			
102	p	0.9		0.25		
120	r		0.65		3	
211	p	0.6	0.3	0.3		
222	p	0.7		0.45		
234	r		0.25			
246	p	0.7		0.4		
253	r		0.3			
296	p	0.7	0.3	0.4		
304	p	0.9		0.2		
332	r		0.7			
396	p	0.7		0.4		
408	r		0.3			
550	p	0.6		0.3		
559	r		0.3		6	debris flow at 674m braids from 707m to 792m log jam at 807m
631	p	1.4		1.1	3	
674	r		0.3		40	
854	p	0.7	0.3	0.4	3	
868	p	0.6		0.35		
876	r		0.25			
926	p	0.7		0.4	1	
943	r		0.3		4	
1078	p	0.7		0.3	4	
1096	r		0.4		7	
1182	p	0.8		0.7		
1211	r		0.1			
1239	p	0.6		0.1		
1251	r	0.5				
1270	p	0.7		0.4		
1285	r		0.3			small log jam channel braids at 1350m fining of bed material at 1403m sand bed sand bed, log jam at 1608m debris flow at 1608 braids from 1674m to 1748m braids from 1772m to 1917m
1308	p	0.8		0.6	10	
1350	r		0.2		1	
1404	p	1	0.2	0.8	1	
1446	p	0.8		0.4	1	
1468	r		0.4		30	
1630	p	N/A			10	
1648	r	N/A			45	
1749	p	0.7		0.4		
1772	r		0.3		30	
1917	p	0.6		0.2		
1928	r		0.4			
1982	p	1.1		0.8		
2002	r		0.3			

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
2021	p	0.9		0.5		
2044	r		0.4		3	
2106	p	0.6		0.2	2	
2120	r		0.4			
2137	p	0.8		0.3		
2147	r		0.5			
2177	p	0.8	0.3	0.5		
2187	p	0.6		0.1		
2192	r		0.5		5	
2254	p	1.1		0.7		
2262	r		0.4			
2312	p	N/A			2	
2316	r		0.4			
2339	p	0.8		0.5		
2355	r		0.3			
2376	p	0.8		0.3	2	
2393	r		0.5		5	
2452	p	1		0.6		
2474	r		0.4			
2491	p	N/A				
2527	r	N/A				
2541	p	1.6		1.3		
2555	r		0.3			
2595	p	0.9	0.45	0.45		
2603	p	1		0.5		
2622	r		0.5		5	
2658	p	0.9	N/A			
2680	p	0.4	N/A			
2714	r			N/A	4	
2747	p	0.7		0.5	2	
2761	r		0.2			
2812	p	1.1		0.8		
2847	r		0.3		5	
2872	p	0.9		0.5		
2882	r		0.4			tributary confluence at 2882m
2948	p	1.1		0.85		
2985	r		0.25			
3001	p	1.1		0.7		
3052	r		0.4		2	
3075	p	1.2		0.85		
3093	r		0.35			
3137	p	0.9	0.4	0.5	2	
3146	p	1.1		0.9		
3160	r		0.2			debris flow at 3160m
3183	p	0.9		0.6		
3191	r		0.3		4	
3214	p	0.7		0.3		
3219	r		0.4			
3419	p	1.1		0.8		
3427	r		0.3		1	

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
3453	p	1.4		1.2	7	
3505	r		0.2		3	debris flow at 3505m
3532	p	1		0.6	1	
3539	r		0.4		5	
3595	p	0.8		0.6	1	
3600	r		0.2		3	
3609	p	0.9		0.6	3	
3621	r		0.3		5	
3759	p	0.8		0.5		
3765	r		0.3			
3772	p	0.6		0.25		
3782	r		0.35		5	
3802	p	0.5		0.2		
3810	r		0.3			
3821	p	1.1		0.7	8	debris flow at 3842
3872	r		0.4			
3903	p	N/A		N/A		
3934	r		N/A		12	
4104	p	0.8		0.4	2	
4117	r		0.4			
4156	p	0.9		0.5	2	
4179	r		0.4		4	
4344	p	0.9		0.5		
4359	r		0.4			
4368	p	1		0.6		
4391	r		0.4			
4502	p	0.8		0.4		
4511	r		0.4		7	
4607	p	0.6		0.3		medium debris flow at 4619m
4630	r		0.3		10	
4692	p	0.8		0.5	12	
4708	r		0.3		8	
4789	p	0.9		0.5		
4798	r		0.4		3	
5072	p	0.9		0.4		
5087	r		0.5			
5130	p	1.1		0.6		
5156	r		0.5			
5345	p	0.9		0.5		
5361	r		0.35		30	major debris flow
5389	p	0.6		0.3	2	
5392	r		0.3		8	
5407	p	0.6		0.25	1	
5413	r		0.35			
5421	p	1.2		0.8		
5431	r		0.4		3	
5441	p	1		0.4	4	
5447	r		0.6		2	
5460	p	0.8		0.4		
5464	r		0.4		3	

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
5524	p	0.8	0.5	0.3		
5533	p	0.8		0.4	1	
5543	r		0.4		2	
5553	p	0.6		0.15	1	
5563	r		0.45		9	
5616	p	0.7		0.4	25	debris flow
5624	r		0.3		4	
5632	p	0.85		0.45	5	
5643	r		0.4		2	
5655	p	0.75		0.3		
5662	r		0.45			
5675	p	0.9		0.3	1	
5684	r		0.6		4	
5791	p	0.7	0.4	0.3		
5798	p	0.65		0.25		
5802	r		0.4			
5810	p	0.9		0.5	1	
5824	r		0.4			
5846	p	0.85		0.4		
5855	r		0.45			
5877	p	0.8		0.4	2	
5892	r		0.4		1	debris flow
5902	p	0.6	0.4	0.2	1	
5907	p	0.65	0.5	0.15		
5919	p	0.6	0.45	0.15		
5936	p	0.6		0.25		
5940	r		0.35			
5953	p	0.8	0.6	0.2		
5959	p	0.7		0.3		
5965	r		0.4			
5971	p	0.6		0.2	1	
5974	r		0.4			
5979	p	0.8		0.45	1	
5982	r		0.35		2	
5987	p	0.5	0.3	0.2	1	
6001	p	0.8		0.3		
6023	r		0.5			
6033	p	0.85		0.25		
6038	r		0.6			
6057	p	0.75		0.25	15	
6072	r		0.5			
6081	p	0.8		0.4	2	
6092	r		0.4		4	
6099	p	0.7		0.4		
6113	r		0.3		7	
6138	p	1	0.2	0.8	3	
6164	p	0.7		0.3	1	
6168	r		0.4		40	
6197	p	0.7		0.3	2	
6213	r		0.4		14	

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
6310	p	0.8		0.3	4	debris flow
6325	r		0.5		5	
6385	p	0.7		0.2	8	
6390	r		0.5		31	
6474	p	0.75		0.35	1	
6497	r		0.4			
6528	p	0.8		0.4	3	
6542	r		0.4			
6562	p	0.5		0.1		
6565	r		0.4		4	
6661	p	1.1		0.7		
6676	r		0.4			
6794	p	0.8	0.4	0.4	2	
6806	p	0.8		0.4	6	
6826	r		0.4		15	
6966	p	0.7	0.4	0.3		
6987	p	0.7		0.2		
7007	r		0.5		2	
7028	p	0.6		0.2		
7039	r		0.4			gauging station at 7040m
7123	p	0.7		0.3		
7129	r		0.4			
7216	p	0.7		0.2	1	
7227	r		0.5			
7255	p	0.8		0.3		bridge at 7325m
7271	r		0.5			
7325	p	0.65		0.35		
7347	r		0.3			
7396	p	0.6		0.35	1	
7400	r		0.25			
7406	p	1.1	0.3	0.8		
7419	p	0.9		0.45	1	
7431	r		0.45			
7437	p	0.7		0.3		
7443	r		0.4			
7465	p	1	0.5	0.5		
7476	p	0.9		0.3		
7485	r		0.6			
7498	p	0.8	0.45	0.35		
7513	p	0.9		0.4		tributary-7571m-Two Bear Crk
7523	r		0.5			
7532	p	0.6		0.1		
7537	r		0.5			
7565	p	0.8		0.3		
7571	r		0.5			
7576	p	0.7		0.2		
7591	r		0.5			
7597	p	0.8		0.3		
7606	r		0.5			
7620	p	1		0.7		

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
7632	r		0.3			
7652	p	0.9		0.4		
7663	r		0.5			
7670	p	0.75		0.25		bridge @ 7670m
7692	r		0.5		3	
7839	p	0.85		0.35		
7858	r		0.5			
7945	p	0.7	0.4	0.3		
7954	p	0.7	0.4	0.3		
7961	p	0.6	0.4	0.2		
7973	p	0.7		0.3		
7985	r		0.4			braids from 7985m to 8005m
8042	p	1.1		0.9		
8071	r		0.2			
8079	p	0.9	0.4	0.5	1	
8091	p	0.9	0.5	0.4		
8102	p	0.5		0.15		
8116	r		0.35			
8138	p	0.9	0.45	0.45		
8154	p	0.8		0.35		
8168	r		0.45			
8182	p	1.1		0.7		
8187	r		0.4			
8216	p	0.7		0.3		
8237	r		0.4			
8287	p	0.8	0.3	0.5		
8302	p	0.75	0.7	0.05		
8326	p	1.1	0.4	0.7		
8337	p	0.8		0.4		
8344	r		0.4			
8412	p	0.8		0.4		
8427	r		0.4			
8431	p	0.7		0.2		
8436	r		0.5			
8489	p	0.7		0.2		
8510	r		0.5			
8517	p	0.7	0.35	0.35		
8523	p	0.7	0.4	0.3		
8540	p	0.7		0.2		
8548	r		0.5			
8692	p	0.9	0.45	0.45	1	
8706	p	0.65	0.4	0.25		
8713	p	0.6	0.4	0.2		
8718	p	0.8		0.4		
8728	r		0.4			
8736	p	0.6	0.35	0.25		
8742	p	0.7	0.6	0.1		
8757	p	0.7	0.3	0.4	1	
8764	p	0.6	0.3	0.3		
8776	p	1		0.7		

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
8789	r		0.3			
8803	p	1	0.5	0.5		
8814	p	0.8	0.6	0.2	1	
8839	p	1.1	0.5	0.6		
8863	p	0.7	0.4	0.3		
8869	p	0.7		0.25		
8884	r		0.45			
8908	p	1	0.45	0.55		
8917	p	0.6		0.2		
8925	r		0.4			
8951	p	0.7		0.4		
8965	r		0.3			
8977	p	0.9	0.55	0.35		
8987	p	0.6		0.2	1	
9002	r		0.4			
9034	p	0.8	0.65	0.15		
9046	p	0.8	0.6	0.2		
9055	p	0.6		0.1		
9061	r		0.5			
9090	p	0.9		0.4		
9107	r		0.5			
9139	p	N/A			6	
9148	r		0.3			
9171	p	0.7		0.2		
9181	r		0.5			
9197	p	0.6		0.2		
9210	r		0.4		1	
9252	p	0.8		0.3		culvert @ 9252m
9259	r		0.5			
9279	p	0.85		0.35		
9293	r		0.5		4	
9318	p	N/A				
9344	r		N/A			
9360	p	1.1		0.8	1	
9379	r		0.3			
9392	p	0.7		0.3		
9397	r		0.4		1	
9421	p	0.8		0.4		
9436	r		0.4		1	
9453	p	0.5		0.2		
9460	r		0.3			
9490	p	0.85		0.45		
9501	r		0.4		2	
9618	p	0.8	0.7	0.1		
9630	p	0.9	0.4	0.5		
9646	p	0.6	0.35	0.25	1	
9656	p	0.75		0.25		
9672	r		0.5			
9704	p	0.7		0.3	2	
9717	r		0.4			

Downstream Distance (m)	Habitat	Max depth(m)	Crest depth(m)	Residual depth(m)	LWD	Comments
9744	p	1.3		0.9		
9770	r		0.4		1	
9783	p	1	0.5	0.5	1	
9798	p	1		0.5		
9806	r		0.5			
9833	p	0.7		0.3		
9840	r		0.4		2	
9906	p	0.9	0.7	0.2		
9917	p	0.8	0.45	0.35		
9926						
						stop at cliff on S.side of road

p = pool
r = riffle